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# PROCEEDINGS OF A WORKSHOP ON RECLAMATION OF DISTURBED LANDS IN ALBERTA

*Edited by*

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# *FOREWORD*

*Human activities have a considerable impact on the landscape. In the past, development in Alberta often proceeded with the simple objective of reaping the maximum benefits, leaving the site abandoned and sterile. Today, there is a growing realization that this need not be so. Properly managed and reclaimed, disturbed lands can be restored to productivity for perpetuity.*

*The Workshop reported in these Proceedings covered essentially all active research and development projects for reclamation of land disturbances in Alberta. The purpose was to provide informal communication and discussion of current programs and results. Thus some material presented was highly preliminary and there has been minimal editing of submissions.*

*Shortly after the workshop, a letter was sent to all participants requesting outlines of planned reclamation and research programs, and suggestions for research priorities. The replies are appendixed to these Proceedings.*

*The editors thank Dr. S.B. Smith, Chairman of the Research Secretariat, and Dr. G.T. Silver, Director of the Northern Forest Research Centre, for support of the Workshop. We also thank Dr. W.B.G. Denyer for his opening address, Mr. D.L. Dabbs for his closing summary, and all participants for making the Workshop a success.*

*D.H.*

*W.R.M.*

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# *AN OVERVIEW*

# DISTURBED ENVIRONMENTS

by

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RESEARCH SECRETARIAT
ALBERTA DEPARTMENT OF THE ENVIRONMENT

## INTRODUCTION

The title of this paper is purposefully vague - it hints of a general approach to the topic of reclamation, lack of knowledge or experience, or an attempt at extensive treatment of problems requiring very intensive applied research. In fact all three major elements will be explored as a background for the discussion to follow.

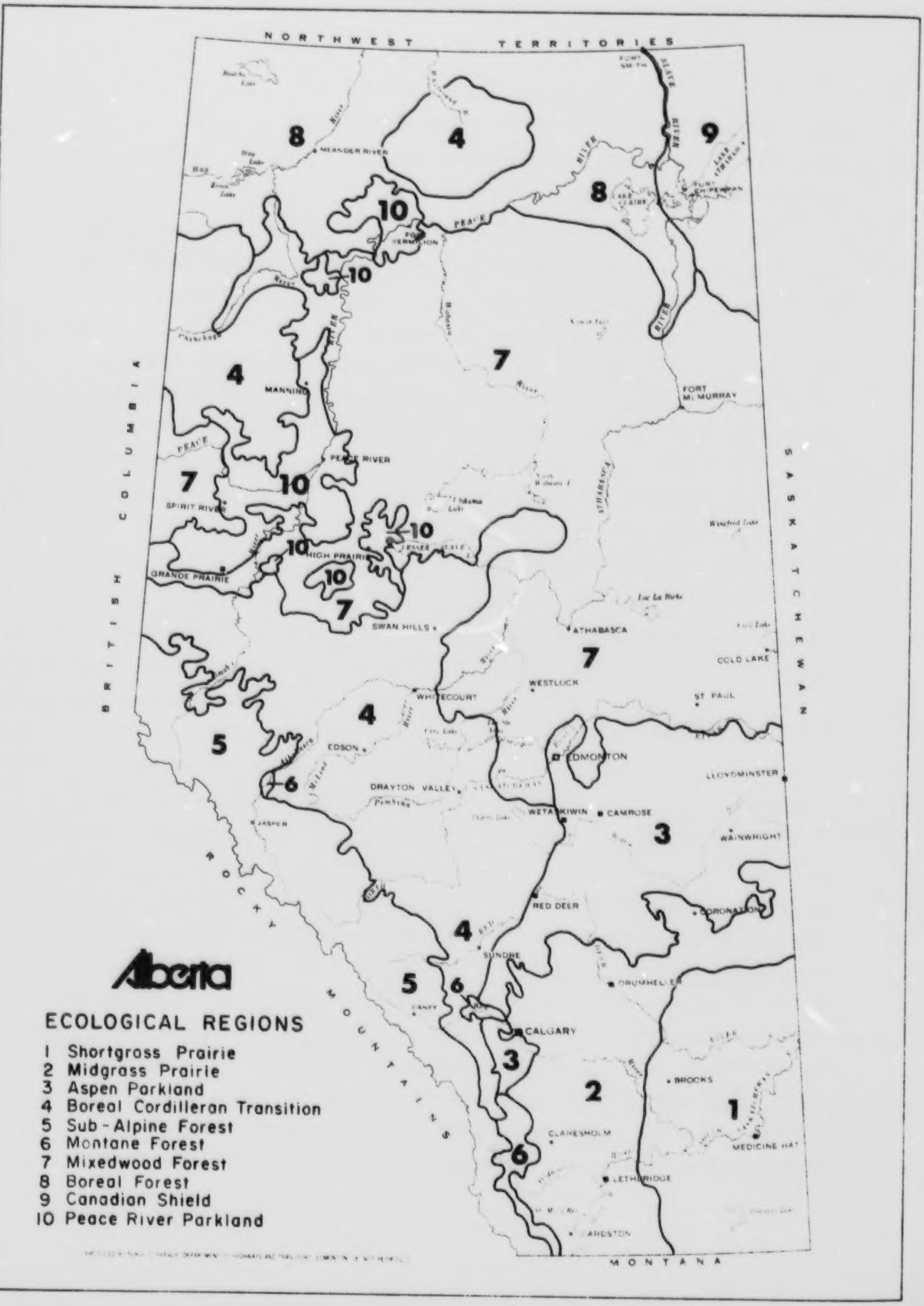
Disturbed environments should require no definition, but we should qualify the discussion by confining our attention to man-made alterations of natural environments, and specifically, physical alteration of the land surface. There are of course, man-induced disturbances to aquatic and atmospheric environments of very great magnitude, but these will not be discussed except in the context of their direct connection with reclamation of disturbed land.

Another factor should also be introduced, concerning the wide environmental diversity to be found in Alberta. In this province, latitude changes from 49 to 60 degrees north; altitude increases from 500 feet to more than 12,000 feet above sea level. At least ten ecological zones can be identified, with large geological and physiographic differences, reflecting also large quantitative and qualitative differences in floral and faunal characteristics. For the present discussion an ecological "map" is used, to illustrate environmental diversity, and to underline the necessity for considering disturbed environments in relation to ecological constraints which must inevitably set the stage for reclamation possibilities. The scheme presented here was derived by J. T. Nalbach, over a period of two years, and in consultation with a large number of resource management agencies. It is contained in the unpublished Multiple Resource Management Guide of the Alberta Department of Lands and Forests.

Finally, it should be mentioned that the economics of reclamation has not been considered in dealing broadly with the subject of disturbed environments. You will hear later this morning how the Land Surface Conservation and Reclamation Act is intended to apply to reconstitution of acceptable environments from disturbed environments. It should be pointed out here, however, that the Act is very broad, and provides wide discretionary powers for the Minister of the Environment. Thus, decisions of reclamation or management of disturbed lands are a matter for public attention, falling outside the normally recognized economic factors which operate in a free market situation. It is probably safe to say that no one knows yet what the people of Alberta will be willing to pay for reconstitution of disturbed environments. Until the legislative and social options are better known, it would probably be unsafe to speculate on the economics of reclamation.

## ECOLOGICAL CONSTRAINTS

As indicated earlier, a number of factors operate to constitute an ecological region. In Alberta, our consideration of land management must relate to the fact that the complexities of biophysical factors have resulted in the widest diversification of types in Canada. Thus we can reasonably assume that over the breadth of the Province we probably are faced with the widest swing in ecological conditions to be encountered anywhere in this country. This is an important point to emphasize, particularly when we attempt to apply results of reclamation research done elsewhere. For instance, reclamation of disturbed land in the Montane Forest zone of Alberta might be attempted in any one of three relatively small geographic areas such as the Porcupine Hills, a portion of the Bow River valley near Cochrane or a portion of the Athabasca River valley at the Jasper Park boundary. Although these


NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
ROCKY MOUNTAINS
FORT SMITH
SLAVE RIVER
LAKE ATHABASCA
FORT CHIPEWYAN
LAKE CLAIRE
MEANDER RIVER
Hay Lake
PEACE RIVER
FORT VERMILION
MANNING
PEACE RIVER
SPIRIT RIVER
GRANDE PRAIRIE
HIGH PRAIRIE
SWAN HILLS
FORT McMURRAY
ATHABASCA
Lac La Biche
COLD LAKE
WESTLOCK
ST. PAUL
WHITECOURT
EDSON
EDMONTON
LLOYDMINSTER
DRAYTON VALLEY
JASPER
WETASKIWIN
CAMROSE
WAINWRIGHT
RED DEER
CORONATION
SUNDRE
DRUMHELLER
BANFF
CALGARY
BROOKS
CLARESHOLM
MEDICINE HAT
LETHBRIDGE
CARDSTON
1
2
3
4
5
6
7
8
9
10
Alberta

ECOLOGICAL REGIONS

1 Shortgrass Prairie
2 Midgrass Prairie
3 Aspen Parkland
4 Boreal Cordilleran Transition
5 Sub-Alpine Forest
6 Montane Forest
7 Mixedwood Forest
8 Boreal Forest
9 Canadian Shield
10 Peace River Parkland

small areas of the Montane Forest are treated as one ecological zone, even within that ecological unit there are wide and obvious differences. Landform, altitude and surficial deposits could be similar at Wainwright and Medicine Hat, yet climatic conditions in the shortgrass prairie zone result essentially in desert conditions at Medicine Hat, while Wainwright is firmly located in Aspen parkland. It may be obvious, but apparently the fact is sometimes overlooked by those who feel that we have sufficient research knowledge, that only detailed information, gathered over a very long time can result in any real expectation of success for reclamation. Further, it should not be expected that much can be derived from reclamation at Lethbridge which can apply at Fort McMurray. Because of the limited amount of reclamation research which has been carried out to date in Alberta, we should not be optimistic that results will be forthcoming in a hurry. In summary, our knowledge of ecological constraints to reclaiming disturbed areas is probably much wider and more soundly based than our knowledge of how to carry out successful reclamation in the fact of those constraints.

## State of the Art

If we accept that our knowledge is deficient in reclamation research and technology, where do we really stand at present? We have strong evidence that surface disturbances from exploitation of non-renewable resources will increase. Petroleum resources (gas, oil), coal and other minerals will continue in very high (and increasing) demand. Expectations are that additional major pipelines will be constructed for transmission of oil and gas. Very large areas will be surface mined for oil-bearing (bituminous) sands. Sub-bituminous thermal coal deposits on the prairies are proven or inferred at a total approximating 40 billion tons; mining of these reserves could eventually disturb 10 million acres of land. Bituminous (coking) coal in the foothills and mountains constitutes less than 10 percent of the total Alberta coal reserves, yet environmental impact of foothill and mountain surface disturbances for exploration and strip mining may be of great significance in ecologically sensitive areas.

The state of knowledge of surface restoration of disturbed environments to a large degree rests on reclamation trials by mining companies, rather than on basic knowledge gained through a strong and well co-ordinated research program. Properly, the efforts of both the Alberta Department of Lands and Forests and the Canadian Forestry Service of Environment Canada should be recognized in carrying out reclamation trials and for assessing results. As well, some mining companies have successfully reclaimed disturbed land. There is a tendency however, for many to infer that the state of research knowledge is adequate, or even extensive, but this simply is not yet true. No very extensive body of reclamation literature exists for Alberta or for that matter elsewhere in Canada.

Some specific lacks of information can be cited:

(1) Virtually nothing has been done to determine genetic factors which could be important in successful establishment of native plant species.

(2) Little published information is available on transport of divalent metallic ions as a result of disruption of surface and underlying strata; no significant amount of knowledge is available as to the absorptive or desorptive characteristics of underlying strata with respect to ground water quality.

(3) No significant amount of research has been done on soils microbiology, aimed specifically at restoring biological productivity of reclaimed lands. Similar lack of knowledge is apparent for soils chemistry in relation to reclamation needs.

(4) Almost nothing is known about the physical problems or costs involved in restoring water tables to surfaces which may be perched well above surrounding terrain, and lying over 100-200 feet of highly pervious materials, as will be the final state of much of the Alberta oil sands following extraction of bituminous ores.

The foregoing does not by any means constitute an exhaustive list; the catalogue of dificiencies could be expanded by several orders of magnitude.

It is difficult to estimate where the most severe future difficulties may lie, particularly when adequate research data do not exist. On the basis of past experience one might guess that for the prairies data will be easier to obtain and successful reclamation may be carried out. Much greater difficulty can be expected in steep foothills or in mountainous areas, as well as in the Alberta oil sands.

## SOME CURRENT ACTIVITY

Lest the discussion up to the present be considered totally negative and pessimistic, we should examine what has been done to date, as well as what may be accomplished in the near future. Many people present today have been involved with some of the things which will be discussed; to them much of what is to follow will be only a cursory glance at the general problems associated with disturbed environments.

First, it should be stated that in-depth evaluation has been given to problems associated with reclamation of the Alberta oil sands. A little over 15 months ago, the Minister of the Environment, the Hon. W. J. Yurko, requested the Conservation and Utilization Committee to establish a task force to define an applied research proposal for reclamation of the mining areas in the oil sands region. The task force was established under the chairmanship of Dr. Green of Alberta Research Council, and drew membership from the Alberta departments of Agriculture, Environment and Lands and Forests; Canadian Forestry Service and Environmental Protection Service of Environment Canada; Alberta Research Council and the University of Alberta. The task force constructed a comprehensive outline of research requirements, dealing broadly with six major elements of reclamation research: (1) Characteristics of tailings deposits, (2) Amelioration (improvement) of tailings, (3) Revegetation, (4) Water quality and water bodies, (5) Materials management, and (6) Natural ecosystems. Research was recommended into the separate and interrelated aspects of the six major elements, some of which have been commenced in a modest way. It is the expectation of the Department to publish this task force report in the near future.

During the past few months, an inter-service committee of Environment Canada has been at work under the aegis of the Regional Board, Prairies and Northern Region and chaired by Drake Hocking of the Canadian Forestry Service. Among several major research recommendations in the committee report is extensive treatment of reclamation research needs for the Alberta oil sands.

A third report, written concurrently with the Environment Canada report, but in no way connected with it, was completed about a month ago in the Research Secretariat of the Alberta Department of the Environment. This latter document also contains extensive examination of reclamation research needs for the oil sands in northern Alberta.

We would expect that a significant response will be generated from companies with an interest in the oil sands when the Conservation and Utilization Committee Task Force report is published. The companies have formed an organization called the Oil Sands Environmental Study Group, which has represented the interests of the corporations involved in the oil sands. It is our expectation that the OSESG will be the single corporate structure with which the Alberta Department of the Environment will co-operate in reclamation research on the oil sands.

Finally, with respect to oil sands reclamation research, a very significant effort has been extended by a multi-disciplinary team at the University of Alberta, in the form of a proposal for accelerated research over the next two or three years.

Proposals have also been received for reclamation research from individuals in the academic community, private consultants, and major corporations.

It would be in error to leave the impression that all reclamation research will be related to the oil sands, although it is obvious that the scope and urgency of development in that area have captured the greatest share of attention. Problems elsewhere than in the oil sands have by no means vanished, and reclamation research needs are no less important for reclamation of surface mines in a variety of locations on the prairies and in the foothills and mountains. As well, several hundred miles of large diameter pipeline could be constructed in Alberta in the near future, as the southern end of the Mackenzie Valley gas pipeline. Geophysical exploration will continue for the foreseeable future, and the new reclamation legislation will result in reclamation of presently active sites as well as older, abandoned sites. Aside from the oil sands, therefore, the stage is set for a high level of activity in reclamation projects, as well as the research on which such activity must be based for successful conclusion.

## PLANNING, CO-ORDINATION, FUNDING AND IMPLEMENTATION

It is all very well to cite an impressive list of planning activities, but the ultimate test of planning is of course the implementation of meaningful programs. In this respect there are at least four phases which must be considered: (1) Research identification, (2) Co-ordination, (3) Funding, (4) Implementation. From our present state of knowledge, it would seem that research identification has proceeded to the extent that phase one is complete enough to proceed to the next step.

Because reclamation legislation falls entirely under Provincial jurisdiction, policy planning and implementation, including co-ordination is primarily a Provincial responsibility. The Minister of the Environment for Alberta has very specific powers and duties under the new Land Surface Conservation and Reclamation Act, one of which is the duty to provide co-ordination. Such activities as may be concerned with actual implementation of reclamation works are clearly spelled out in the Act. Co-ordination of reclamation research programs are not spelled out in legislation, and as a consequence, require special effort. The Research Secretariat has been given the responsibility to ensure that Alberta and Federal Government agencies, universities, consultants and industry pool their efforts in the complicated, time consuming and expensive task of establishing good programs, with a minimum of duplication.

If co-ordination of planning and research programs is achieved, funding participation must be part of the overall plan. There are some things that some agencies can do better than others, and responsibility for certain aspects of overall programs can be assigned. Shared-cost programs are notoriously difficult to run, unless an agreement can be reached to utilize an apparatus acceptable to everyone. In the case where both Federal and Provincial jurisdictions may be involved, matters are more complicated. In the present case, reclamation is clearly enough a Provincial responsibility that agreement for funding between governments and industry should not be too difficult. It seems that the almost traditional adversary position of industry and resource management agencies of government has almost disappeared, and fundings of research and management programs for restoration of disturbed environments will become simply a matter of routine negotiation.

I have deliverately left the matter of implementation of programs to the last, because chronologically that is the way it will happen, but perhaps more importantly to provide a focal point at this workshop for civil servants, academics, consultants and industry representatives. I want to suggest a way in which I think we can get the most for the reclamation dollar, as well as providing the greatest satisfaction and benefits to those who are involved. Probably there will not result a consensus from the following suggestions, but it seems to me to be a logical conclusion and solution to a complex problem.

(1) Government should take the primary responsibility for identification of research problems associated with disturbed environments. Interdepartmental, interdisciplinary task forces appear to be appropriate mechanisms for construction of initial position papers and policy planning documents.

(2) Because legislation exists to provide a vehicle for co-ordination, government agencies should be given the responsibility for co-ordination of research programs and field trials.

(3) Funding should be a matter of negotiation between government and the industry causing disturbance of the environment. Costs involved in research and implementation should be considered an integral

part of the cost of the industrial operation. Where government clearly has the best expertise available that expertise should be used; otherwise, it should be drawn from outside government.

(4) When agreement has been reached on funding, implementation should generally be removed from the control of civil servants, except for provision of statutory requirements; the role of civil servants from this point on should be as qualified observers and advisors.

Disturbance to natural environments will become more frequent and more extensive as we continue to exploit our resources. We have developed effective legislation to provide a vehicle for restoration and mangement of disturbed areas. Sufficient examination of reclamation research problems has taken place so that government, industry and the academic community should now be ready to implement high quality reclamation programs. Sharply accelerated research effort is the first prerequisite; without that effort widespread success in reclamation of disturbed environments is unlikely.

# *PROBLEM DEFINITION AND REGULATION*

# Remote Monitoring of Environmental Change

by

C. L. Kirby[1]

New remote sensing tools such as improved films, cameras and lenses, multispectral and thermal scanners, side-looking radar and microwave systems, to name a few of the most useful at present, are increasing our ability to monitor environmental change.

The earth resources technology satellite (ERTS) launched in July, 1972, is inspiring a new look at the total environment. The ERTS experiment, with its multispectral scanner, has been so successful that a second identical ERTS will be launched early in 1975. A new series of earth observation satellites (EOS) will be launched in 1978. These satellites will have improved resolution and spectral bands including thermal sensing.

Small-scale aerial photography obtained from altitudes up to 40,000 feet above sea level has also been demonstrated to be a useful monitoring tool and provides resource inventories such as forest inventories at greatly reduced costs. Increased accuracy in interpretation even with small-scale aerial photography is achieved with the use of infrared-ektachrome film where colours clearly define muskegs, hardwood, softwood and other forest and land types as well as areas where vegetation has been killed.

Infrared line scanners mounted in aircraft for detecting thermal anomalies are being used increasingly for the detection of forest fires and thermal pollution in lakes and streams, to name two applications.

Imagery may be obtained at night or during the day. Comparisons

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[1] C.L. Kirby, Forestry Officer, Environment Canada,
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of day and night imagery obtained over exposed rock areas can reveal different rates of cooling which may be associated with rock types.

Correlating spectrometers operating from aircraft or from ground vehicles are capable of detecting air pollution and mapping its extent.

Side-looking radar has the ability to penetrate cloud cover and map large areas. This imagery may be geometrically rectified and provide base maps showing surface features of streams, roads and relief. Applications in monitoring sea ice conditions and ocean oil spills appear to be promising.

Passive and active microwave systems are also being tested and some success in determining soil moisture and evaluating snow depths has been achieved.

This brief account indicates some of the instrumentation and its application. Research and development of applications is carried on at N.F.R.C. on ERTS, thermal scanning, small and large-scale aerial photography. With improved technology there is no excuse for fragmented views of the environment. Man's intuitive desire for unity and harmony with the environment is being assisted by remote sensing. Perhaps the medium is changing the message and now man is more aware of his environmental problems with necessary information for intelligent action. With these new tools comes an increasing need for multidisciplined remote sensing centres, serving managers and a public concerned with the environment.

# THE EFFECT OF PIPELINE INSTALLATIONS ON CROP YIELD

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## Introduction

In 1966 we had an opportunity to determine the effect on crop yield of soils disturbed by the 1965 installation of an oil pipeline between Ft. Saskatchewan and Clover Bar. The trench dug was 24" wide and 48" deep and topsoil and subsoil were mixed. Sampling of crops along the pipeline right-of-way through mostly black Malmo silty clay loam revealed no significant loss of yields on ten farms (with the exception of one case), and in some cases significant improvement of yield over the pipeline. (See Table 1), Reasons for yield increase include the possibilities that tilth was improved and that mineral nutrients had been brought up from the subsoil.

In 1968 this project was extended to determine the effect of trenching operations and pipe installations on crop yields on other soils in the Edmonton area.

## Procedure

Cereal crops along the routes of several recently installed gas and oil pipelines in the Edmonton area were examined for uniformity of stand and suitability for sampling. Immediately prior to harvesting by the farmers cooperating in this study, the pipelines were located with a Fisher M-Scope Tracer. In most cases, twelve paired samples of one square yard area were taken every 50 ft. along the pipelines right-of-way. Test samples were taken directly above the pipeline and, to ensure being off the right-of-way, controls were taken 50 ft. to the side of the pipeline, on alternate sides where possible. The bagged samples were dried, threshed, and grain and straw weights taken. The Student paired t-test was utilized to determine statistical difference.

## Results and Discussion

The 1969 growing season in the Edmonton region was poor, with insufficient precipitation during the first half and wet, cold weather during the second half of the season. This resulted in finding very few fields suitable for sampling, with the majority of these selections, for reasons mainly of "patchy" growth, actually below the standard preferred for reliable sampling.

Table 2 illustrates the results obtained for the seven fields sampled. In all cases grain yield was significantly greater over the pipeline than off the pipeline right-of-way. Straw yields were not usually significantly different, since although the grain was usually taller over the pipeline, there were fewer plants per unit area than in the remainder of the field.

## Conclusions

Pipeline installations in all soils tested, with the possible exception of Solonetzic soils, did not appear to damage soil fertility. In fact, in 1968, as in 1966, there was a general improvement in yield over the trenched areas of pipeline right-of-ways. Examination of Alberta Soil Survey data for the soils involved reveal that increased yield could not be attributed to change in texture, and therefore improvement of tilth and the bringing to the surface of subsoil minerals provide the most likely explanations.

However, it is felt that deep trenching in Solonetzic soils with a high level of sodium salts in the parent material could be harmful. That the measured results in 1968 were contrary to this conclusion probably resulted from the fact that tillage for the pipeline right-of-way was more extensive than in the remainder of the field.

Trenching operations where gravel, rocks or stones are brought to the surface would obviously cause problems. Apart from this it appears that trenching operations do not seriously impair production of our common cereal crops in soils of the Edmonton area.

Table 1. Effect of a pipeline installation in black chernozemic soils of the Clover Bar - Ft. Saskatchewan area near Edmonton on yields in bu/ac.

YIELDS 1966

| FIELD | CROP | CHECK | PIPELINE | DIFF. |
|---|---|---|---|---|
| 1 | Wheat | 69.3 | 62.1 | - 7.2* |
| 2 | Wheat | 39.5 | 28.5 | -11.0 |
| 3 | Wheat | 43.8 | 46.3 | + 2.5 |
| 4 | Oats | 60.0 | 70.6 | +10.6* |
| 5 | Oats | 54.4 | 68.2 | +13.8* |
| 6 | Barley | 60.0 | 60.6 | + 0.6 |
| 7 | Barley | 28.7 | 35.8 | + 7.1* |
| 8 | Barley | 54.2 | 62.3 | + 8.1* |
| 9 | Barley | 27.5 | 26.0 | - 1.5 |
| 10 | Barley | 49.2 | 52.7 | + 3.5 |

* Statistically different at P=0.05.

Table 2. Effect of pipeline installations in other soils in the Edmonton area on crop yields.

YIELDS 1968

| FIELD | CROP | CHECK | PIPELINE | DIFF. |
|---|---|---|---|---|
| 11 | Wheat | 35.4 | 44.4 | + 9.0** |
| 12 | Wheat | 29.6 | 41.6 | +12.0** |
| 13 | Wheat | 22.1 | 29.6 | + 7.5* |
| 14 | Barley | 39.0 | 52.9 | +13.9* |
| 15 | Barley | 44.2 | 72.5 | +28.3** |
| 16 | Barley | 46.2 | 56.7 | +10.5* |
| 17 | Barley | 26.4 | 35.9 | + 9.5* |

* Statistically different at P=0.05
** Statistically different at P=0.01

Details of Soils and Pipelines

| Field | Soils | Pipeline Installation |
|---|---|---|
| 11 | Orthic Dark Grey | 6 5/8" gas, 20" x 40" trench, 1965 |
| 12 | Eluviated Black and Orthic Dark Grey | 24" oil, 30" x 64" trench, 1958 |
| 13 | Black Solodized Solonetz and Black Solod | 34" oil, 40" x 74" trench, 1967 |
| 14 | Eluviated Black | 16" oil, 24" x 48" trench, 1965 |
| 15 | Black Solodized Solonetz and Eluv. Black | 24" oil, 30" x 64" trench, 1958 |
| 16 | Eluv. Black and Dark Grey Wooded | 24" oil, 30" x 64" trench, 1958 |
| 17 | Black Solodized Solonetz and Eluv. Black | 34" oil, 40" x 74" trench, 1967 |

# PROBLEMS OF CHLORIDE AND HEAVY METAL CONTAMINATION

by

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## ABSTRACT

Contamination with chloride salts comes from salt water spills from the oil extraction industry, atmospheric dispersal from drying stacks of potash plants and salting of roads during winter de-icing. Contamination with heavy metals comes from mineral ore processing, smoke releases and tailings wastes and other industrial and combustion sources. Both classes of contaminant are non-biodegradable and have high potential for causing injury and death to vegetation, for rendering soil non-productive and for impairment of water quality. Contamination can occur rapidly within limited areas (as from a spill) or gradually, usually over a large area (as from a constant release of an aerial emission containing low concentrations).

Land contaminated with salts or heavy metals usually cannot be restored to productivity by any known *in situ* treatments (excepting chlorides on very well-drained soils) because the contaminants are not significantly broken down or utilized by soil microorganisms. Reclamation procedures therefore consist of attempts at leaching, selection of resistant plant species, or deep burial of the contaminated soil. There is some prospect of chemically complexing the contaminants to produce stable non-toxic substances and rendering soil productive again.

# APPLICATION OF THE LAND SURFACE CONSERVATION AND RECLAMATION ACT

D.G. Harrington

Alberta Environment

## INTRODUCTION

The only reclamation legislation that was in effect in Alberta prior to 1973 was the Surface Reclamation Act. This Act was administered by the Department of Mines and Minerals until it was transferred to the Department of Environment in 1971. The Act is limited to surveyed lands in the province and therefore, does not apply to all lands within Alberta. In addition, it is largely restricted to operations in the oil and gas and mining industries. This Act will be repealed upon proclamation of part 3 of the Land Surface Conservation and Reclamation Act.

The Land Conservation and Reclamation Act applies to all lands within Alberta except those lands used for residential purposes or agricultural operations, and therefore no agricultural operation or residential use of lands may be designated as a surface=disturbing operation. Where a regulated surface operation impinges on residential land use or agricultural operations, the Act applies. A surface disturbance means (1) the disturbance exposure, covering, or erosion of the surface of the land in any manner or (2) the degradation or deterioration in any manner of the surface of the land. It is recognized that agricultural operations are for the purpose of conserving and improving physical and chemical properties of the soil and therefore have been exempted. Those lands used for residential purposes do not impose a problem individually and it would be unrealistic to expect home owners to receive approval to develop and reclaim private lots. The crown is also bound by the act and must receive approval for any designated surface disturbance.

The act contains four parts, of which parts 1 and 2 and part of 4 have been proclaimed.

For the purpose of this discussion we will attempt to highlight the important features under each part.

PART I GENERAL

Part I of the Act deals with the functions of the Minister of the Environment. The Minister of the Environment may enter into an agreement with owners of land for the purpose of restricting use for the preservation of watersheds, shorelines, watercourses,and valley breaks. (Compensation by the government for loss of use to the land owner must be provided for in any agreement.)

The Minister may also order the preparation and submission of an environmental impact assessment. The purpose of the assessment is to evaluate the effect of any operation on the conservation, management, and utilization of natural resources in the area, the pollution of natural resources, the noise resulting from the operation and its effect on the surrounding environment, the economic factors that directly or indirectly affect the ability of the applicant to carry out measures that relate to the proceeding, and finally the preservation of natural resources for their aesthetic, wilderness, and recreational value. The assessment should also clearly indicate those measures or alternatives that are available to reduce environmental impact.

In the event that any person has not complied with or has contravened any provision or order of the act, the Minister may issue a Stop Order. This may result in a hearing being called by the Environment Conservation Authority upon appeal by the person receiving the Order.

The Minister may also issue a Restricted Geophysical Operations Order for the restriction of geophysical operations within any specified area of the province or during any specified period of the year. Such an order could restrict activity within wilderness areas as established under the Wilderness Areas Act, or Provincial Parks. They could also designate that clearing will be done during the winter months when the ground is frozen and there is a protective snow cover.

In the event that there will be environmental degradation from a mining operation, the Minister may recommend to the Lieutenant Governor in Council that the Minister of Mines and Minerals be authorized to acquire by exchange, purchase, or expropriation any interest in mines and minerals.

Under Part I a Land Conservation and Reclamation Council is established consisting of a Chairman from the Department of the Environment, a Deputy Chairman from the Department of Lands and Forests and a Deputy Chairman from the Department of Mines and Minerals. The staff of the Council consists of a secretary plus inspection and reclamation officers. In addition each county or municipality may appoint two local members and each regional planning commission may also appoint one member for their area. Before a Reclamation Officer may issue an order for the additional work or a reclamation certificate releasing the applicant from further responsibility it must also be signed by a local member.

The provision is made for financial assistance in the form of grants or loans to restore derelict lands or to prevent lands from becoming derelict. There are in Alberta many abandoned coal, quarry, and gravel pit operations where the government is responsible for reclamation. Many of these areas can be landscaped and reclaimed for farming, grazing, land fill sites, parks, or other land uses.

It has been recognized in the past that operators have had to deal with several departments of government to obtain approvals. This haphazard type of operation has caused delay and confusion for the operators, and in many cases duplication in the review and application of regulations to the development. This Act make referral and co-ordination by government mandatory. In this way applications are automatically referred to departments involved for their input. Inputs are co-ordinated and wherever necessary meetings are held with the applicant before final terms and conditions are set. Referral and co-ordination procedures will be discussed in more detail later in the paper.

## PART 2 APPROVALS FOR REGULATED SURFACE OPERATIONS

The main provisions of this part of the Act require that before any designated surface operation may commence the applicant must submit plans and specifications giving details of development and reclamation procedures for approval. Any person operating on activity designated as a surface disturbance without an approval will be subject to a "surface disturbance control order."

Regulations covering this part of the Act will prescribe the content of plans and specifications, referral procedures in processing the applications, and the amount, nature and kind of the security deposit required.

Those operations that may be designated by regulation as surface disturbing operations are:

(a) the drilling, operation or abandonment of a well;

(b) the construction, operation or abandonment of a pipeline battery, transmission line or telecommunication line;

(c) the opening up, operation or abandonment of a mine or quarry;

(d) the opening up, operation or abandonment of a pit or of a waste disposal site or land fill site;

(e) geophysical operations that result or will result in surface disturbance;

(f) the construction, operation or abandonment of a mineral processing plant, road, railway or aircraft landing strip;

(g) the construction, operation or abandonment of any structure (including a micro-wave tower) forming part of a broadcasting undertaking as defined in the Broadcasting Act (Canada);

(h) the construction, operation or abandonment of a site for subsurface disposal of solid or liquid waste;

(i) the conduct of examinations and surveys on land made in connection with water or the conduct of exploration in respect of surface and subsurface water;

(j) the construction of any works for the impoundment, conveying or diversion of water;

(k) the preparation of land to be used for the purpose of industrial sites or for recreational development;

(l) the excavation and removal of top soil or peat for the purposes of sale;

(m) the excavation and removal of archaelogical findings;

(n) any alteration of or extension of any operation or activity referred to in clauses (a) to (m).

A unique feature of this part of the Act is the provision for transfer and delegation of administration to other Departments. In Alberta public land administration coincides to a great extent with the Green, Yellow and White Zones of the province. Crown land has been designated as Green, Yellow and White. The Green Zone is administered by the Alberta Forest Service, the Yellow and White Zones are administered by the Lands Division. At the present time the Department of Lands and Forests is responsible for land conservation and reclamation of crown lands. The Surface Reclamation Council is responsible for reclamation in the surveyed area which is primarily in the White and Yellow Zones but as mentioned before has largely to do with the oil and gas and mining industries. There has been duplication of administration, and more seriously, varying standards of reclamation criteria. By delegating the authority of this Act to departments presently involved with the work, duplication should decrease and reclamation criteria will be uniform under one regulation. In other words, operators will only have to deal with one act and set of regulations as far as surface disturbances are concerned in any agency.

## PART 3 RECLAMATION ORDERS AND CERTIFICATES

Part 3 of the Act deals with reclamation orders and certificates. This part applies to lands that have been used for activities designated as surface-disturbing operations, referred to earlier. There is also provision for the transfer and delegation of authority enabling other departments and agencies to issue reclamation orders and certificates.

The standard of reclamation will be provided by regulation under

Part 3 so that all agencies to whom authority has been delegated will be using the same reclamation criteria.

Reclamation Officers will have the authority to issue reclamation orders during operations to reclaim land on or adjacent to the right-of-way, remedy any hazard to human life, domestic livestock or wildlife, or the repair of any fences, culverts or other structures.

Before a surface lease or right-of-entry order is terminated, the operator must be in receipt of a reclamation certificate. The purpose of the reclamation certificate is to ensure that the reclamation conforms with the development approval and also that all parties are satisfied. In the event that the owner or operator is not satisfied a review may be requested up to thirty days following this issue of a certificate. Following the review by Council members not involved in the issue of the original certificate plus a member from the Regional Planning Commission, an order may be issued to do additional work or the original certificate may stand. If either the owner or the operator is still not satisfied then the decision may be appealed to the district court.

## REGULATIONS

The Land Conservation Regulations under Part 2 will be proclaimed shortly. These regulations set out the terms of reference for the establishment of committees, their memberships, powers, duties and functions with respect to the review of applications and plans for Exploration Approvals and Reclamation and Development Approvals. The regulations also prescribe Land Conservation Guidelines which will generally apply to any operation or activity that is designated to be a regulated surface operation under any regulated Surface Operations Regulations.

In respect to security deposits the regulations empower the review committees to recommend the type and amount of deposit to the approving authorities. The sale or leasing or transfer of approval of any Regulated

Surface Operation is prohibited without the consent of the appropriate approving authority.

There are three committees established under the Land Conservation Regulations: the Crown Mineral Disposition Review Committee, the Exploration Review Committee and the Development and Reclamation Review Committee. It is important to note here that these committees are operative now and have been for several years. In the past membership was determined by need and gradually over the years a full membership has evolved. These regulations in effect formalized what has proved to be workable. The membership of the committees include members from

a) the Department of Agriculture
b) the Department of Environment
c) the Department of Highways and Transport
d) the Department of Industry and Commerce
e) the Department of Lands and Forests
f) the Department of Mines and Minerals
g) the Department of Municipal Affairs
h) the Energy Resources Conservation Board and
i) the Research Council of Alberta

The Crown Mineral Disposition Committee reviews applications for the purchase of crown mineral rights prior to advertisement and sale. The purpose of the review is to identify areas of conflict and recommend either special conditions of sale or removal of lands from the sale where there will be excessive environmental damage. The main areas of concern are shorelands, riverbanks, watercourses and areas located within parks or wilderness areas.

In the event that the Minister of Mines and Minerals does not agree with the recommendations of the committee he may direct the Chairman of the Review Committee to refer the matter to the Natural Resources Co-ordinating Council for a recommendation. The membership of the Natural Resources Co-ordinating Council consists of Deputy Ministers responsible for natural resource management.

The Exploration Review Committee considers each application referred to it for its environmental impact and sets terms and conditions to minimize environmental damage and provide for reclamation upon completion of the exploration program.

The committee must make its recommendations within 30 days of receiving the application to the approving authority.

Terms and conditions would pertain to such things as location and width of trails and access roads, location of test holes, clearing requirements including salvage of timber, disposal of waste materials, location and type of stream crossing, erosion control and final reclamation.

The Reclamation and Development Review Committee recommends to the approving authority that a Reclamation and Development approval be granted or refused within 90 days of receiving the application.

An application for a Reclamation and Development approval will when prescribed consist of the following reports and or plans:

a) A Land Use Report which outlines the impact of the proposed development on existing and alternate land uses in the area.

b) A Surface Disturbance Report outlining areas to be cleared and excavated and the location of discard material.

c) A Geotechnical Report consisting of a stability analysis for any loaded slope or overburden, tailings, spoil or discard deposits based on foundation investigations and the properties of the material involved.

d) A Surface Water Management Report with sufficient detail to permit evaluation of changes in water flows including flood frequency patterns, control, diversion and drainage structure.

e) A Groundwater Management Report with sufficient detail to project the effect of the proposal of groundwater quality, availability, and regime.

f) A Water Quality Management and Pollution Control Report giving a comprehensive review of measures to reduce suspended solids to an acceptable level.

g) An Air Quality and Noise Pollution Management Report specifying the impact of the operation in respect of air contamination by visible or particulate emissions, and noise levels and the methods of control to achieve acceptable levels.

h) A Reclamation Report outlining the schedule of reclamation to be followed, the final condition and use of the site, type and method of revegetation and a landscape illustration showing the final features after total reclamation.

There has been developed in Alberta a set of Land Conservation Guidelines. These guidelines were developed by an interdisciplinary group for the primary purpose of protecting key watershed areas such as riverbreaks, water courses, and shorelands. Since their inception they have been modified and improved to the point where they are now well accepted by resource managers, regional planning commissions, and the general public. The guidelines have been included in the Land Conservation Regulations as a schedule and are a guide to all committees when dealing with any particular designated surface operations.

The guidelines provide protection against erosion on steep or long gradual slopes by requiring the maintenance of vegetation in key locations and specified patterns. Distances are specified to ensure that developments or surface disturbing activities do not encroach on riverbreaks, shorelands, or watercourses.

This discussion has not by any means dealt with all of the details of the Act and Regulations;however, we hope that the concept of interdisciplinary co-ordination and decision-making has been conveyed. People in government and industry often complain about the number of referrals they have to contend with but if we were to continue to make decisions in isolation this would in my view only increase referrals. The main difference would be that referrals generated from decisions made in isolation would deal primarily with conflicts, crisis and complaints, whereas referrals generated from interdisciplinary committees deal with review of applications that will lead to approvals containing practical terms and conditions that will protect the environment.

# *SOME FIRST PRINCIPLES AND METHODS*

# SOME BASIC DATA WITH RESPECT TO COAL MINE WASTE RECLAMATION

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The purpose of this paper is twofold: (1) to acquaint you with the project "Environmental Geology - Mountain Coal Mining" and some of the data from that study and (2) to demonstrate that the collection of data of this type is both beneficial and necessary to the development of a reclamation technology. The approach to any problem follows three basic steps: recognition and definition, data gathering and analysis, and finally the proposal of a solution. This study at the moment is somewhere between stage 2 and 3.

The initial phase of study of the geological, geomorphological, and hydrogeological factors affecting mountain coal resource exploration, exploitation and subsequent reclamation was carried out during the 1972 field season. Reconnaissance and data gathering were restricted primarily to the Crowsnest Pass-Elk Valley area of Alberta and British Columbia. The location and extent of all surface mining activity and most underground mining, both past and present, were mapped in the Crowsnest (82G/10 E and W) Blairmore (82G/9W) and Tornado Mountain (82G/15W) map-areas. Thirteen surface mine locations with over thirty-five individual pits were examined in detail as well as the sites of former activity of fourteen underground mines. Waste rock dumps in each area were examined and data on aspect, profile, stability, associated deposits, composition, active geomorphic processes, vegetation, and dates of operation were recorded. Analysis of this information resulted in the formulation of a set of objectives for the study. These were:

1. To develop a mapping technique which would convey to engineers and planners in the coal mining industry, the distribution and engineering characteristics of surface materials.
2. To conduct, and in some cases develop, suitable tests to characterize the physical nature of coal mine waste, particularly in light of the increased scale and extent of mining and the need for compliance with legislated environmental restraints.
3. To investigate the active natural processes affecting coal spoil and document the relationship between these processes and reclamation.

With that brief introduction I will now present some data and conclusions with respect to the three headings above.

1. Mapping Techniques

A flexible mapping system was adopted and is being tested in three 1:50,000 sheets in the Crowsnest-Elk Valley area of B. C. Units are chosen on the basis of more or less traditional divisions (i.e.) alluvial, lacustrine, till, etc. These are represented on the map and in the legend by capital letters. Small letters following the cap designated the landform unit i.e., terrace, fan, moraine. A small letter preceeding the cap designated texture i.e. gravelly, sandy, clayey etc. The designation of a gravel river terrace would be gAt (gravelly Alluvium terrace). This system is not new and not nearly as complex as might first be thought. In order to present engineering information on the legend, the major map units are described in terms of their engineering properties, and rated for suitability as aggregate source, building site, road or rail bed location, erosional stability etc. These maps should be ready for publication sometime in the Fall of 1974.

2. Physical Characteristics

I want to discuss briefly six physical properties measured in the field: 1) temperature 2) bulk density 3) water content 4) infiltration rate 5) grain size 6) lithic composition.

1) Temperature

Lack of tree cover of south and southwest facing slopes, better survival rates for trees and grasses in protected micro-elements and stem burns on saplings suggested that coal spoil can become extremely hot. Selecting a fine coal spoil with an ash content of 30%, laboratory studies reveal a thermal conductivity equivalent to loose snow and a specific heat close to the value of iron. Temperatures as high as 164°F were recorded on south facing 26° slopes. Maximum recorded temperatures for eight aspects reveal there is a 50°F difference of maximum temperature between south and north aspects for slopes of 26°. Further studies reveal that material and aspects are the prime temperature control with slope being less important and elevation not having a noticeable effect.

## 2) Bulk Density

Two factors influence in-place bulk density of spoil-composition and compaction history. For the same compactional history, (in this case a proctor mold test) weathered rock and till have a bulk density of 114 lbs. per cubic foot while a sample of bituminous coal had a density of 65 lbs. per cubic foot. The following table summarizes the data collected:

| Material | Compaction History | yd range (lbs/ft$^3$) |
|---|---|---|
| Weathered bedrock, till and spoil | dump platform | 100-115 |
| Weathered bedrock till and spoil | free face | 85-100 |
| Carbonaceous shale and sandstone | dump platform | 70-90 |
| Coarse coal refuse | wheel compacted | 75-80 |
| Carbonaceous shale and sandstone | free face | 60-70 |
| Highly Carbonaceous Shale | free face | 50-65 |
| Bituminous Coal | in place | 60 |
| Tailings Lagoon | deposits from slurry | 45-55 |

With respect to reclamation, as bulk density and therefore compaction goes up, the infiltration and permeability of water goes down. Also it is difficult for plant roots to penetrate into the highly compacted areas.

## 3) Water Content

Water content measurements reveal coal spoil capable of holding considerable quantities of water. Average moisture content at 4 to 6 inches rarely drops below 10%. Fine coal tailings have averages of 16% at this level. Water is rarely available from the water table for plant maintenance, because it is deep and the capillary rise through spoil rarely exceeds 2 ft.

## 4) Infiltration Rate

A concentric rig infiltrometer was used to measure infiltration rates for various spoil and tailings materials. This device measures the rate at which the ground surface will accept water. This information is useful in explaining why there is so little gullying and rill formation on "most" spoil piles and is useful in designing infiltration galleries and other devices to prevent surface erosion. The information is summarized in the following table:

| Location | No. of Readings | Average (in/hi) |
|---|---|---|
| Tailings ponds | 12 | 2.3 |
| Pit Roadways | 4 | .63 |
| Coarse spoil | 8 | 1.87 |
| Till, weathered rock | 2 | .26 |

The infiltration rate of the tailings pond materials is equivalent to the grassland area overlying glacial gravels. The till is considerably less likely to infiltrate, the water having a rate equivalent to that of row crops in a medium textured soil. The data indicates that on tailings ponds and coarse spoil infiltration rates are above the rate of precipitation for most summer storms; however, compacted pit roadways and finer grained spoil derived from the weathered surface rock will not take up the rainfall, but will allow overland flow and therefore gullying.

5) Grain Size

Complete grain size analysis was made of 30 samples down to 44 micron. These data were used to support other studies and classify the material.

6) Lithic Composition

Tailings from the cleaning plants were analysed for lithic composition by microscopic examination of the sand fraction. An average of 74% of the particles were identified as coal or highly carbonaceous shale. Samples examined average 40% ash. Waste rock is more variable. Based on drill logs the average spoil pile should contain 5% unconsolidated overburden (i.e. till, weathered rock), 55% shale and carbonaceous shale and 40% sandstone. With respect to reclamation it is the sandstone waste that presents the major challenge because of size and resistance to breakdown at the surface.

## 3. Active Natural Processes

The active natural processes on which data has or is being gathered include:

1) Rock weathering at the surface
2) Rill and gully formation
3) Size sorting on spoil dumps
4) Dump stability and foundation strength
5) Dump stability and ground water flow
6) Dump surface drainage
7) Landslides in waste rock
8) Downslopes surface movement. (The biological angle of repose.)

The last two on the list are by far the most important and will be discussed briefly.

If coal spoil has no cohesion - and it certainly appears that way - then the angle of internal friction must be close to the angle of repose 37%. If that is the case there should be no large scale failures — this is conventional engineering wisdom. For any calculation you might make the factor of safety more than one one those cracks 40 to 50 feet back from the edge of the dump. However, failures where the failure plane is confined wholly within the spoil are becoming frequent as pile size grows.

One area of our research has been devoted to understanding the factors affecting such failures. The failure begins as a crack. Movement on this failure plane becomes sufficient that operations must stop. The rate of movement increases; this is the accelerating creep phase. Finally failure takes place. I offer the following theory on failure: On an active dump, settlement at the outer edge may create an initial fracture. The movement of this outer slice relative to the rest of the pile becomes localized along a planar zone 40 to 50 feet back from the crest and emerging about 200 feet down the slope. As movement takes place stress is built up in the interlocking rocks in the movement zone. The weaker of these break, straightening the fracture zone and causing movement. This increases the stress on the interlocked blocks which remain in place. Eventually the weaker of these also break. Thus as the fracture plane develops, fewer key blocks are locked across the zone of movement. Finally the remaining interlocking blocks are no longer capable of supporting the weight of the wedge and it fails. An interesting observation to support this theory was the sound of rocks breaking at depth recorded eight hours prior to a major landslide. This theory I have labelled "strain softening".

Given that "in spoil" failures do take place, how can they be minimized? Observation indicates the probability of failure is greatest when:

1. the rate of dumping is high
2. the dump platform is wide
3. the edge of the dump is accurate

The next step in this investigation is to construct a computer model of dump failure to determine certain engineering parameters.

Dump failure by landslide is a major problem during and immediately following placement, but becomes less important with respect to reclamation, because the solution to a more critical problem "down slope surface movement" automatically solves the landslide problem.

Let me define a new term to discuss this problem - "Biological Angle of Repose". At slope angles approaching the angle of repose the surface layer of material on a slope is too active to allow the establishment of plants. The rate of growth of the plant root system is not rapid enough to allow it to anchor itself against the slow downhill movement of the soil cover. As the slope angle is decreased from the angle of repose, movement rates and volumes decrease, until a point is reached where plants can colonize the surface. This point is the "Biological Angle of Repose". As with physical angles of repose its value varies with conditions, and although perhaps not as sharply defined, it is a useful concept. Observation of numerous spoil piles in the Crowsnest Pass Area indicates that the "Biological Angle of Repose" lies between 25-30$^{0}$: 7$^{0}$ to 12$^{0}$ less than the physical angle of repose.

This summer we attempted some crude measurements of just how much material actually moved down these slopes. Surface movement was measured by constructing sediment traps on the slopes. The amount of movement is expressed in terms of grams per 24-hour day of material that would pass across an imaginary line one meter long lying across the strike of the slope. For coal spoil of sand and pebble-sized material, rates ranged from 30g/day/meter for a slope of 28 degrees to 160g/day/meter for slopes of 35 degrees. On an extremely active slope of 37 degrees, values as high as 1600g/day/meter were recorded. Movement of material was recorded over an average of 60 days, and was found to occur at irregular intervals. Particles moved downslope as slopes dried and were subjected to wind disturbance. Small mudflows were observed during one intense summer storm.

Flexible tubes perpendicular to the slope indicated that transport of material occurred in the upper 5 cm. Surface movement on spoil slopes is a function of slope angle and material: most movement seems to occur as discrete events. These measurements coupled with observations from various abandoned spoil piles indicate that surface movement of individual particles is sufficiently rapid on slopes greater than the biological angle of repose to seriously jeopardize revegetation efforts. In conclusion let me mention three recommendations:

1. Slopes on waste piles be reduced to the biological angle of repose where revegetation is required. This is most economically achieved by placing material during mining in such a manner as to facilitate reclamation. The contour dumping system could be adoped at many mines.
2. South slopes should be planted to grass and a nursery crop (annual) in early spring and tree species not be introduced until grass cover is well established.
3. All areas above dumps, but especially compacted roads and dump platforms be drained away from spoil dumps.

# UTILIZATION OF WASTE MATERIALS FOR SOIL FORMATION

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Although there are numerous methods of disposing of wastes very few of these utilize the constituents contained therein. Some wastes appear to have value in establishing vegetation on disturbed areas.

1. Liquid wastes presently presenting a disposal problem are municipal sewage effluent, gas plant scrubbing liquid, cheese whey, vegetable processing wastes and meat packing plant wastes. All contain relatively low amounts of organic matter and varying amounts of plant nutrients. They can be classed as high volume - low concentration wastes and present a transportation problem. Penn State has had tremendous success in establishing growth on mine spoil material with sewage effluent. Only in rare circumstances would these wastes be economically feasible for reclamation in Alberta.

   Semi-liquid and solid wastes are relatively low volume - high concentration materials with a lesser transportation problem. Sewage sludge, the most common except for animal wastes, has a nutrient value of approximately three dollars per dry ton; it contains a large percentage of organic matter but also is relatively high in heavy metals. Its value on agricultural land is limited as the organic matter has only slight value, it's an expensive source of nutrients compared to chemical fertilizers and continual application could result in a build-up of heavy metals in the plant product.

Attention is now shifting towards using sludge as a non-agricultural growth promoter for landscaping and reclamation. The high organic content, well-balanced nutrients which are released slowly, the absence of weed seeds and the low concentration of salts make sludge almost ideal for reclaiming mine refuse materials. The one-shot application and the limited agricultural use of most reclaimed areas will minimize any possible ill effects caused by heavy metals in the plant material. Two recent trials in Alberta have shown that digested sewage sludge has great potential for establishing growth on coal mine refuse.

# Sulfomethylated Humic Acids as Fertilizers and Soil Conditioners for Restoration of Sandy Soils*

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## ABSTRACT

Experiments were conducted with the ammonium salt of water-soluble sulfomethylated humic acids to determine its performance as fertilizer and conditioner on sandy soils located at Youngstown, Alberta. Ammonium nitrate and ammonium sulfate were used as nitrogen fertilizer standards for comparison. The ammoniated sulfomethylated humates had pronounced improving effects on the physical properties of sandy soil, but they did not exert any substantial effect on plant growth beyond that attributable to their nutrient content.

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## INTRODUCTION

The interest in the development of organic-based fertilizers and soil conditioners lies in the fact that organic matter, "humus," is one of the main constituents of soil. The amount of organic matter in soil is a variable quantity. In very sandy soils, the concentrations are small; in peat the organic content may exceed 50% by weight. The amount of organic content is also a function of the soil's origin, age, previous treatment and general morphology of the terrain, etc. It is well known that soil humus is an essential constituent of all fertile soils and, in addition to the role of a storehouse of plant nutrients, it improves the physical structure of the soil through a binding effect. Humus renders phosphorus and other elements soluble by a buffering action which prevents rapid changes of pH (1).

Recent studies (2, 3, 4) in the use of humates as fertilizers have provided increasing evidence that humic acids, after application to the plant-root environment, are capable of causing a stimulated absorption of specific nutrients (e.g., phosphorus, potassium, iron). They have also been found to promote root initiation (4, 5) and to exert marked physiological effects upon plant organisms (6).

Peats and lignites are composed mainly of humic acids, while mature coals are easily converted to humus materials by mild oxidation. Since humic acids derived from coal resemble those present in soils, it follows that coal humus may be utilized to increase the organic matter and fertility of soils. The present study was conducted to determine the properties of the ammonium salt of sulfomethylated humic acids (7, 8, 9) as fertilizers and soil conditioners for sandy soils.

## MATERIALS AND METHODS

Elemental analyses of soil and plant samples were carried out by the Alberta Department of Agriculture, Soil and Feed Testing Laboratories, employing common analytical techniques (10). The moisture content of soil at 1/3 bar (250 mm pressure) was determined with a pressure plate extractor.

Low-grade, weathered (naturally oxidized) subbituminous coal from the upper seam at Sheerness, Alberta (locally known as rusty coal), with an alkali-soluble humic acid content of 80 to 85%, was used for the various batch productions of water-soluble sulfomethylated humic acids (11, 12). The analyses of the parent humic acids and a number of their sulfomethylated products are given in Table 1. Ammonium nitrate (34-0-0) and ammonium sulfate (21-0-0) (Elephant Brand, Cominco) were used as nitrogen fertilizer standards for comparison with the sulfomethylated humates.

## Field Plot Experiments

The ammoniated sulfomethylated humic acids were field tested on sandy soils located at Youngstown, Alberta, in comparison with ammonium nitrate and ammonium sulfate. Three treatments were applied, of 56, 112, and 224 kg per hectare on the basis of available nitrogen, with three replicates for each treatment.

The plots were seeded with bromegrass and rye on May 18, 1972. The land was ploughed prior to fertilizer spreading in each plot, and then was seeded with a mechanical seeder. Plots of 3 meters by 3 meters were arranged in a randomized block, with spaces of 3 meters between each plot. Rainfall was above normal during May and normal during June, July and August.

Samples of .836 $M^2$ (1.0 $yd^2$) were harvested from each plot on August 16 and September 7, 1972, to determine the variations in nitrogen uptake of the different treatments. The harvested plant materials were dried at 50 °C and their dry weights recorded. The final harvest, after separation of the weeds,* was threshed and grain and straw weights were determined. The plots were not sprayed with herbicide to destroy weeds before seeding, consequently a substantial growth of weeds occurred, especially on fertilized plots.

Soil samples were obtained from each plot (15 cm depth) before treatment and after harvesting to determine if the amounts of available nitrogen varied between treatments.

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*Mainly the genus of Chenopodium of the family of Chenopodiaceae.

## Soil Structure Experiments

Sandy soil from the same location (Youngstown, Alberta) was used for the determination of the soil's physical properties. For all studies, it was air dried and sieved through a 2 mm screen.

Aggregate Analyses: Sulfomethylated humic acids were applied to the soil at rates of 0.27%, 0.54%, and 2.7% by weight. The additives were mixed with 500 grams of soil and placed in an aluminum dish 15 cm in diameter and 4 cm deep. Eight replicates of each treatment were kept at 10 °C to 20 °C, and watered to 5.9% moisture content by weight every week for five weeks. Aggregation was measured by the wet sieving procedure (13).

Hydraulic Conductivity Experiments: Hydraulic conductivity ("Falling-Head" method (13)) was determined in duplicate on 300 grams of soil in 4 x 45-cm glass tubes, filled by pouring the soil from a standard height and saturating it by soaking the bases of the tubes in distilled water.

Hydraulic conductivity was determined of aqueous solutions (200-ml head) of each treatment (ammonium nitrate, sulfomethylated humate and ammonium sulfate), of 300 ppm and 600 ppm nitrogen content applied to the surfaces of the soils in the columns.

Leaching Rate Experiments: Forty grams of soil was placed into each 2.5 x 25-cm glass tube fitted with a stopcock and a sintered glass disc to support the soil. Tubes were filled by pouring the soil from a standard height. On top of the columns was placed another 10 grams of soil mixed with nutrient to provide 100 and 200 ppm of nitrogen per gram of soil. Completed columns were saturated by adding distilled water in portions from the top.

To determine leaching rates, 35 ml (8 cm) of distilled water was poured on top of the saturated columns and left for 24 hours. The water in each tube was allowed to drain until it had reached the level of the soil surface, and the leaching time was recorded. The same procedure was repeated twice for each tube. Salts and humate contents were determined on the combined leachates from each tube.

Ammonium nitrate and ammonium sulfate were determined by electrical conductivity (10). Sulfomethylated humates were determined spectrophotometrically. A Beckman DB-G grating spectrophotometer was used.

## RESULTS AND DISCUSSION

### Field Plot Experiments

Dry matter yields of plants before and at maturity (Table 2), nitrogen content of the plants at the two growth stages (Table 3) and soil analyses (Table 4), show that all plots gave poor yields and low nitrogen uptake (Table 5) in comparison to yields and nitrogen recoveries which were obtained using the same and other fertilizers in various other soils (14, 15). Grain yields from ammonium sulfate treatments were significantly higher than yields from the other treatments (Table 2), among which there was little variation.

Total yields (Table 2) of plots treated with ammonium sulfate and sulfomethylated humates were significantly higher than yields of plots treated with ammonium nitrate. This may be atrributable to sulfur, the extra nutrient which was supplied to the soil by the ammonium sulfate and sulfomethylated humic acid fertilizers.

Aggregate Analyses: Water-stable aggregation is an important characteristic of agricultural soils. Sandy soils are noncohesive and do not agglomerate by themselves to form stable aggregates. They are easily drifted by strong winds and are susceptible to water erosion from rainfall. Sulfomethylated humates at rates of 0.54% and 2.70% by weight significantly increased the meaningful diameters of aggregates from 0.21 mm (control) to 0.57 mm and 1.56 mm; respectively, approximately threefold to sevenfold (Table 6).

Hydraulic Conductivity: The hydraulic conductivity of sandy soils is very high; consequently water infiltrates rapidly, carrying with it all the vital plant-growth nutrients. Plants growing on soils with high infiltration rates are restricted by limited water and nutrient supplies around their root environment.

Sulfomethylated humates significantly decreased the hydraulic conductivity of sandy soils (Table 7).

Leaching Rates: Sulfomethylated humates decreased the leaching rates by approximately 10 minutes and 30 minutes, respectively, for the two rates of application (Table 8). Also, the ammonium nitrate and ammonium sulfate were totally leached out, in contrast to leaching of only 66% and 35% of the sulfomethylated humates. These results suggest a binding mechanism, probably through hydrogen bonding, between the hydroxyl groups of humates and sandy soils.

Moisture Retention: Sulfomethylated humates substantially increased soil moisture content (Table 9).

## CONCLUSIONS

Results of this study have shown that:

1. At the same levels of nitrogen per hectare, the sulfomethylated humic acids gave yields comparable to those of ammonium sulfate.
2. Yields of ammonium nitrate-fertilized plots were lower than those of other treatments at the same levels of nitrogen per hectare. This may be attributed to the extra nutrient (sulfur) which was supplied by the other treatments.
3. Yields from sandy soils were poor in comparison to yields obtained using the same and other fertilizers in various other soils. Nitrogen recovery was also low for all treatments.
4. The results have substantiated previous findings* (14, 15) and have shown that at the same level of nitrogen, the sulfomethylated humates' effects on plant growth are comparable to those of other nitrogen-carrying fertilizers.
5. The sulfomethylated humic acids significantly increased soil aggregation and moisture-holding capacity and reduced hydraulic conductivity and leaching rates.

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*S. Dubetz, Personal communication, Canada Dept. of Agriculture, Lethbridge, Alberta (1971).

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Table 1. Analysis of humic acid and sulfomethylated humic acid product

| Analyses results (%) | Feed* | Product |
|---|---|---|
| Moisture | 25.2 | 5.3 |
| Ash | 12.9 | 17.9 |
| Carbon | 39.1 | -- |
| Hydrogen | 2.2 | -- |
| Sulfur | 0.4 | 2.0 |
| Nitrogen | 1.3 | 5.3 |
| Dist. $NH_3$ | -- | 3.7 |
| Dry basis: | | |
| Carbon | 52.2 | -- |
| Hydrogen | 2.9 | -- |
| Sulfur | 0.5 | 2.1 |
| Nitrogen | 1.7 | 5.5 |
| Nitrogen (dist. $NH_3$) | -- | 3.9 |

*Weathered subbituminous coal from Sheerness, Alberta, - locally known as "rusty coal."

Table 2. Yields of rye grown at Youngstown, Alberta site

| Treatment | Nitrogen applied (kg/ha) | -Yield of dry matter (3 replicates)- before maturity (August 16, 1973) (100 kg/ha) | | | --------Yield of dry matter (3 replicates)-------- at maturity (September 7, 1972) (100 kg/ha) | | | |
|---|---|---|---|---|---|---|---|---|
| | | Weeds | Straw | Weeds+Straw | Weeds | Straw | Grain | Weeds+Straw+Grain |
| Control | 0 | $0.65^{d}$ | $13.0^{b}$ | $13.7^{c}$ | $0.23^{f}$ | $9.29^{c}$ | $2.49^{c}$ | $12.0^{d}$ |
| Ammonium nitrate | 56 | $3.14^{d}$ | $12.6^{b}$ | $15.8^{c}$ | $1.52^{f}$ | $10.3^{c}$ | $5.19^{b}$ | $17.0^{c}$ |
| Sulfomethylated humate | 56 | $6.00^{c}$ | $16.7^{b}$ | $22.7^{b}$ | $3.93^{de}$ | $11.4^{abc}$ | $3.34^{bc}$ | $18.7^{c}$ |
| Ammonium sulfate | 56 | $5.98^{c}$ | $16.9^{b}$ | $22.8^{b}$ | $5.76^{c}$ | $16.6^{a}$ | $2.91^{c}$ | $25.3^{b}$ |
| Ammonium nitrate | 112 | $5.57^{c}$ | $14.3^{b}$ | $19.7^{c}$ | $3.18^{e}$ | $9.17^{c}$ | $3.90^{bc}$ | $16.2^{c}$ |
| Sulfomethylated humate | 112 | $5.52^{c}$ | $14.9^{b}$ | $20.4^{bc}$ | $7.64^{b}$ | $11.4^{abc}$ | $2.86^{c}$ | $21.9^{bc}$ |
| Ammonium sulfate | 112 | $9.10^{b}$ | $15.8^{b}$ | $24.9^{b}$ | $7.35^{bc}$ | $12.2^{abc}$ | $7.34^{a}$ | $26.9^{ab}$ |
| Ammonium nitrate | 224 | $6.76^{c}$ | $16.3^{b}$ | $23.1^{b}$ | $5.16^{cd}$ | $11.6^{abc}$ | $3.78^{bc}$ | $20.6^{c}$ |
| Sulfomethylated humate | 224 | $7.89^{b}$ | $22.5^{a}$ | $31.2^{a}$ | $9.12^{ab}$ | $11.6^{c}$ | $3.26^{bc}$ | $22.5^{b}$ |
| Ammonium sulfate | 224 | $11.4^{a}$ | $23.4^{a}$ | $34.8^{a}$ | $8.28^{a}$ | $15.2^{ab}$ | $7.16^{ab}$ | $31.7^{a}$ |
| Standard error of the mean ($S\bar{x}$=): | | 1.59 | 1.50 | 1.58 | 0.46 | 1.70 | 0.58 | 1.84 |

* Values not followed by the same letter in a column are significantly different at the 95% level of probability as judged by Duncan's Multiple Range Test.

Table 3. Nitrogen analysis of plants grown at Youngstown, Alberta, site

| Treatment | Nitrogen applied (kg/ha) | Plants harvested before maturity (August 16, 1972) | | | Plants harvested at maturity (September 7, 1972) | | | |
|---|---|---|---|---|---|---|---|---|
| | | ---------Nitrogen (kg/ha)--------- | | | ---------------Nitrogen (kg/ha)--------------- | | | |
| | | Weeds | Straw | Weeds+Straw | Weeds | Straw | Grain | Weeds+Straw+Grain |
| Control | 0 | 1.71 | 9.14 | 10.8 | 0.54 | 6.33 | 5.89 | 12.8 |
| Ammonium nitrate | 56 | 6.79 | 13.8 | 20.6 | 3.73 | 8.34 | 13.0 | 25.1 |
| Sulfomethylated humate | 56 | 14.3 | 14.0 | 28.3 | 8.16 | 8.53 | 6.96 | 23.6 |
| Ammonium sulfate | 56 | 13.4 | 19.4 | 32.8 | 8.82 | 10.9 | 6.57 | 26.3 |
| Ammonium nitrate | 112 | 14.7 | 17.5 | 32.1 | 8.02 | 9.54 | 10.7 | 28.2 |
| Sulfomethylated humate | 112 | 15.9 | 14.7 | 30.6 | 16.8 | 7.84 | 6.94 | 31.6 |
| Ammonium sulfate | 112 | 30.6 | 19.9 | 50.5 | 16.2 | 9.31 | 18.7 | 44.2 |
| Ammonium nitrate | 224 | 18.5 | 21.5 | 40.0 | 13.9 | 12.7 | 11.0 | 37.5 |
| Sulfomethylated humate | 224 | 28.3 | 25.6 | 54.0 | 21.9 | 8.44 | 8.89 | 39.3 |
| Ammonium sulfate | 224 | 37.8 | 35.2 | 73.0 | 23.1 | 14.8 | 20.6 | 59.0 |

Table 4. Soil test data of field sites at Youngstown, Alberta

| Treatment | Nitrogen applied (kg/ha) | --- kg/ha---- N | P | K | Na[1] | S (ppm) | pH | Organic[2] matter | Texture[3] |
|---|---|---|---|---|---|---|---|---|---|
| Control | 0 | 9 | 30 | 803 | low- | 1.1 | 5.7 | low- | 1 |
| Ammonium nitrate | 56 | 10 | 27 | 666 | low- | 2.1 | 5.7 | low- | 1 |
| Sulfomethylated humate | 56 | 14 | 30 | 753 | low- | 8.1 | 5.5 | low- | 1 |
| Ammonium sulfate | 56 | 9 | 30 | 644 | low- | 4.0 | 5.4 | low- | 1 |
| Ammonium nitrate | 112 | 39 | 31 | 638 | low- | 1.5 | 5.4 | low- | 1 |
| Sulfomethylated humate | 112 | 10 | 30 | 635 | low- | 24.1 | 5.4 | low- | 1 |
| Ammonium sulfate | 112 | 12 | 24 | 652 | low- | 15.3 | 5.2 | low- | 1 |
| Ammonium nitrate | 224 | 46 | 28 | 647 | low- | 2.2 | 5.3 | low- | 1 |
| Sulfomethylated humate | 224 | 22 | 29 | 646 | low- | 31.5 | 5.4 | low- | 1 |
| Ammonium sulfate | 224 | 24 | 28 | 622 | low- | 72.3 | 4.9 | low- | 1 |
| L.S.D. at 95% level of probability | | 8.5 | 5.6 | 193 | | 24.0 | | | |

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[1] Low-: 0 to 7 ppm.

[2] Low-: less than 0.5 to 1%.

[3] Texture 1: sand

Table 5. Recovery of applied nitrogen in crops (rye and weeds) at two stages of growth and in the soil after harvest, Youngstown, Alberta site

| Treatment | Available N applied (kg/ha) | Net recovery of applied nitrogen* | | | | |
|---|---|---|---|---|---|---|
| | | In crop before maturity (kg/ha) | In mature crop (kg/ha) | In soil Sept. 7 (kg/ha) | Recovery in mature crop (%) | Total recovery in mature crop + soil (%) |
| Control | 0 | 0 | 0 | 0 | 0 | 0 |
| Ammonium nitrate | 56 | 9.8 | 12.3 | 1.0 | 22.0 | 23.8 |
| Sulfomethylated humate | 56 | 17.5 | 10.8 | 5.0 | 19.3 | 28.2 |
| Ammonium sulfate | 56 | 22.0 | 13.5 | 0 | 24.1 | 24.1 |
| Ammonium nitrate | 112 | 21.3 | 15.4 | 30.0 | 13.8 | 40.5 |
| Sulfomethylated humate | 112 | 19.8 | 18.8 | 1.0 | 16.8 | 17.7 |
| Ammonium sulfate | 112 | 39.7 | 31.4 | 3.0 | 28.0 | 30.7 |
| Ammonium nitrate | 224 | 29.2 | 24.7 | 37.0 | 11.0 | 27.5 |
| Sulfomethylated humate | 224 | 43.2 | 26.5 | 13.0 | 11.8 | 17.6 |
| Ammonium sulfate | 224 | 62.2 | 46.2 | 15.0 | 20.6 | 27.3 |

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[*] Calculated as nitrogen in fertilizer treatment minus in control.

Table 6. Effect of sulfomethylated humates on mean weight diameter (MWD) of aggregates

| Treatment | Application (%) | Sandy soil MWD (mm) |
|---|---|---|
| Control | 0 | 0.21 |
| Sulfomethylated humate | 0.27 | 0.23 |
| Sulfomethylated humate | 0.54 | 0.57 |
| Sulfomethylated humate | 2.70 | 1.56 |
| L.S.D. at 95% level of probability | | 0.02 |

Table 7. Effect of various treatments on the hydraulic conductivity of sandy soil from Youngstown, Alberta

| Material | Nitrogen in solution (ppm) | Depth of water infiltration (cm/min) | | |
|---|---|---|---|---|
| | | I | II | average |
| Control | distilled water | 0.26 | 0.26 | 0.26 |
| Ammonium nitrate | 300 | 0.18 | 0.18 | 0.18 |
| Sulfomethylated humate | 300 | 0.11 | 0.11 | 0.11 |
| Ammonium sulfate | 300 | 0.14 | 0.14 | 0.14 |
| Ammonium nitrate | 600 | 0.13 | 0.13 | 0.13 |
| Sulfomethylated humate | 600 | 0.03 | 0.03 | 0.03 |
| Ammonium sulfate | 600 | 0.11 | 0.12 | 0.12 |
| L.S.D. at 95% level of probability | | | | 0.01 |

Table 8. Effect of various treatments on leaching rates of sandy soil from Youngstown, Alberta

| Treatment | | | Leaching times for 35 cc solution* | | | Materials in leaching solutions (grams) |
|---|---|---|---|---|---|---|
| Material | Soil (g) | Amount (g) of material to provide 100 and 200 ppm of N for each gram of soil | 1st leaching (min.) | 2nd leaching (min.) | Total leaching (min.) | |
| Control | 50 | - | 14 | 20 | 34 | - |
| Ammonium nitrate** (35 %N) | 50 | 0.0142 | 18 | 22 | 40 | 0.015 |
| Sulfomethylated humate ( 3.7%N) | 50 | 0.1350 | 27 | 23 | 50 | 0.090 |
| Ammonium sulfate (21 %N) | 50 | 0.0238 | 20 | 23 | 43 | 0.027 |
| Ammonium nitrate (35 %N) | 50 | 0.0284 | 15 | 21 | 36 | 0.025 |
| Sulfomethylated humate ( 3.7 %N) | 50 | 0.2700 | 35 | 35 | 70 | 0.095 |
| Ammonium sulfate (21 %N) | 50 | 0.0476 | 13 | 20 | 33 | 0.046 |

* L.S.D. at 95% level of prabability = 0.78

** Reagent grade

Table 9. Effect of sulfomethylated humic acids on moisture-retention of sandy soils from Youngstown, Alberta

| Material | Humic acids in soil (%) | Moisture retention (%) |
|---|---|---|
| Control | 0 | 5.9 |
| Sulfomethylated humic acid | 0.4 | 6.38 |
| Sulfomethylated humic acid | 0.8 | 8.89 |
| Sulfomethylated humic acid | 1.0 | 7.68 |
| Sulfomethylated humic acid | 2.0 | 10.27 |
| Sulfomethylated humic acid | 4.0 | 12.76 |
| Sulfomethylated humic acid | 8.0 | 19.17 |
| Sulfomethylated humic acid | 10.0 | 19.13 |

# RECLAMATION OF SOILS AND WATERS MADE ACID BY WINDBLOWN SULPHUR DUST

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## INTRODUCTION

Approximately 5 million tons of elemental S are produced annually in Alberta from processing of sour natural gas. The storage, handling and loading of elemental S give off sulphur dust that may be carried onto adjacent land by wind. In soil, elemental S may be oxidized to $H_2SO_4$ causing acidification. To date there are probably less than 1,000 acres of land in Alberta that have been damaged by windblown sulphur dust. However, where damage exists it is usually serious; soils are barren, very acid (pH 2 to 4), prone to wind and water erosion, and they make runoff water extremely acid.

## NATURE OF THE PROBLEM

Sulphur dust in soils is quickly converted to $H_2SO_4$ by sulphur-oxidizing bacteria. After an initial lag period in which the number of sulphur-oxidizers builds up, soils under field conditions can convert at least 5 tons per acre of S to $H_2SO_4$ annually. The rapid oxidation of S is demonstrated by results in Table 1, which show that after 1 year the neutralizing effect of an application of 20 tons $Ca(OH)_2$ per acre had mostly been overcome by oxidation of S contained in an acidified soil.

Table 1. The pH of acidified soil, containing 10% elemental S, at various times after application of $Ca(OH)_2$ mixed with the soil to a depth of 6 inches in the field.

| | pH of the top 6 inches of soil | | | |
|---|---|---|---|---|
| Treatment | Oct., 1971* | June, 1972 | July, 1972 | Oct., 1972 |
| None | 2.0 | 2.1 | 1.9 | 2.0 |
| $Ca(OH)_2$ at 10 tons/acre | 6.5 | 4.6 | 2.6 | 2.2 |
| $Ca(OH)_2$ at 20 tons/acre | ** | 5.5 | 5.3 | 2.8 |

* Time at which lime was applied  ** Not determined

When sulphur dust falls on non-cultivated land it oxidizes more slowly lying on the soil surface than when mixed into the soil through cultivation. However, within 2 or 3 years after a heavy dustfall most of the sulphur will have been oxidized even when lying on the soil surface.

Sulphur dust in the amount of 2 or 3 tons per acre will acidify most soils to the extent that there is little or no vegetation, and that amount of sulphur can be oxidized within a year or two, whether the soil is cultivated or not. When deposits of elemental S do not exceed 2 or 3 tons per acre, the soil will be made acid to a depth of a few inches, but when deposits are heavier excess $H_2SO_4$ leaches down to acidify the soil to depths of 1 foot and more. An example of depth of acidification of soil which received heavy depositions of elemental S is given in Table 2.

Table 2. Depth of acidification, and lime requirement of a non-cultivated Black soil (loam texture) which received heavy deposits of windblown sulphur dust.

| | | Lime requirement (tons $CaCO_3$/acre) | | |
|---|---|---|---|---|
| Soil depth (inches) | Soil pH | For present acidity | For unreacted elemental S | Total |
| 0-1 | 1.4 | 3 | 49 | 52 |
| 1-7 | 2.2 | 20 | Nil | 20 |
| 7-13 | 3.4 | 10 | Nil | 10 |
| 13-19 | 4.3 | 6 | Nil | 6 |
| Total lime requirement for top 19 inches of soil | | | | 88 tons |

Elemental S continues to be oxidized in soils until they become too acid for activity of sulphur-oxidizing bacteria (at approximately pH 2). However, as soon as acidified soils containing unreacted elemental S are neutralized by liming, the sulphur-oxidizers again rapidly convert elemental S to $H_2SO_4$. Consequently, in reclaiming sulphur-acidified soils by liming enough lime must be added to counteract both the present acidity and the acidity which will be generated by the unreacted elemental S. The amounts of lime needed may be large (Table 2), and some acidified soils need as much as 300 tons $CaCO_3$ per acre.

The problem we first encountered with severely acidified soils was to find a type of liming material and a method of application which would result in rapid restoration of the soils without harmful side-effects. Another problem was to abate acid run-off water, and how to treat sloughs where not only the water but also the slough bottom soil had become extremely acid.

## Results and Discussion

### 1. Liming of acidified soils

A number of results on methods of determining lime requirement, type of liming material, and methods of application have been reported in detail elsewhere ( 2 ). Those results showed the following.

(i) Treatment of severely-acidified soils with $CaCO_3$ immediately restored their ability to grow normal plants. However, it was necessary to thoroughly incorporate the $CaCO_3$ to a depth of 6 inches or more and to apply enough $CaCO_3$ to neutralize the present acidity of the soil plus enough to counteract the acidity produced by oxidation of elemental S contained in the soil. After treatment with $CaCO_3$ soils were normal in their chemical characteristics; and plants grown on treated soils were within a normal range in their contents of N, P, K, S, Ca, Mg, Fe and Zn, and normal in ratios of N:S and Ca:Mg.

(ii) The only suitable liming material was $CaCO_3$. Other liming materials either caused soil salinity through formation of soluble sulphate salts, or resulted in too high a soil pH. The source of $CaCO_3$ used in liming of acidified soils was commercial ground limestone, and it was found necessary to use limestone with less than 5% $MgCO_3$ by weight to avoid formation of soil salinity. Use of $Ca(OH)_2$ raised pH so high that soils remained barren.

(iii) In deeply-acidified soils plant roots penetrated only as deeply as the $CaCO_3$ was mixed into the soil. Incorporating $CaCO_3$ to a depth of 6 inches gave fair plant growth, although plants were very drought-sensitive because of their shallow rooting depth. However, if $CaCO_3$ is applied at rates in excess of those needed to neutralize the top soil, the $CaCO_3$ worked in to a depth of only 6 inches will slowly diffuse downward to neutralize underlying subsoil. Results show this process will take only 2 or 3 years in very porous sandy soils, but will probably require 5 to 10 years in less porous soils higher in clay content.

2. Reclamation without cultivation of the soil

Two conditions have been encountered under which it would be preferable to reclaim soils without cultivation to incorporate $CaCO_3$. The one condition is acidified woodland where many trees were still alive but where grasses and other undergrowth had been killed by the acidity. (Grass can not tolerate soil pH values much below 4.5 to 5.0, while poplar trees apparently tolerate soil pH values as low as 3.5 without immediate damage.) Reclamation of such areas is necessary because they generate very acid run-off water and because the bare soil under the trees is very subject to water erosion. Reclamation without working the soil to incorporate $CaCO_3$ would be an advantage because trees could be left standing to lessen erosion and also to reduce downwind movement of sulphur dust if sulphur dust is still being deposited. In treed areas $CaCO_3$ can either be broadcast or possibly worked into the soil to a depth of 1 to 2 inches without damaging the tree growth. However, undergrowth would be re-established only after the $CaCO_3$ subsequently diffused downward to give a neutralized rooting zone. A recently-completed field experiment on an acidified wooded soil showed significant increase in soil pH to a depth of 10 inches during a 10-month period following incorporation of $CaCO_3$ to a depth of only 1 inch (Table 3). This experiment indicates that acidified wooded areas can be reclaimed by mixing heavy rates of lime into the top inch of soil and allowing the $CaCO_3$ to diffuse downward to neutralize the soil. The other possible technique for wooded areas is simply to spread lime on the soil surface, but our experiments to measure rate of downward diffusion with that technique are not yet complete. The other condition where reclamation without cultivation would be preferable is slightly-acidified natural grassland still retaining partial grass cover and subject to severe wind and water erosion on cultivation. In such areas the only method of treatment compatible with preserving existing cover is surface application of $CaCO_3$. A recently completed experiment (Table 4) showed an increase in soil pH to a depth of 2 inches during a 10-month period after application. That experiment indicates that surface application can be used to treat slightly-acidified areas where acidity has extended to a depth of only 2 or 3 inches.

Table 3. The pH of different soil depths 10 months after shallow and deeper incorporation of $CaCO_3$ in an acidified soil of loam texture in a wooded area. (Treatment applied June, 1973 and soil sampled April, 1974.)

| Soil depth (inches) | Soil pH of different treatments | | |
|---|---|---|---|
| | No treatment | 100 tons $CaCO_3$/acre worked 1" deep | 200 tons $CaCO_3$/acre worked 6" deep |
| 0-2 | 2.67 | 6.70 | 7.11 |
| 2-4 | 2.95 | 5.83 | 7.10 |
| 4-6 | 3.20 | 3.73 | 6.52 |
| 6-8 | 3.64 | 4.14 | 4.83 |
| 8-10 | 3.94 | 4.44 | 4.50 |

Table 4. The pH of different soil depths 10 months after surface application of $CaCO_3$ to slightly-acidified natural grassland, with a soil of sandy loam texture. (Treatments applied June, 1973 and soil sampled April, 1974.)

| Soil depth (inches) | Soil pH | |
|---|---|---|
| | No treatment | 15 tons $CaCO_3$/acre surface applied |
| 0.1 - 0.5 | 4.2 | 6.4 |
| 0.5 - 1.0 | 4.3 | 4.8 |
| 1.0 - 2.0 | 4.6 | 4.9 |
| 2.0 - 4.0 | 5.4 | 5.4 |
| 4.0 - 6.0 | 5.6 | 5.6 |

Our field experiments have demonstrated a problem with surface application of lime at rates of more than 10 or 15 tons per acre. A thick lime layer at the soil surface is a poor medium for germination of seeds, and also has a low water infiltration rate.

## 3. Fertilizer requirements of reclaimed soils

Plants grown on acidified soils reclaimed by liming do not have unusual fertilizer requirements except for nitrogen. Soils that have become so acid that they support no plant growth usually have a build-up of plant-available nitrogen. (Our results have given values ranging from approximately 100 to 400 lb N per acre.) On soils containing little or no unreacted elemental S at time of liming, the nitrogen remains available for use by plants. However, when soils contain about 1% or more of unreacted elemental S and receive heavy applications of $CaCO_3$, nitrogen contained in the soil (as well as added fertilizer nitrogen) may be rapidly consumed by the action of the sulphur-oxidizing bacteria. This results in extreme nitrogen deficiency of plants grown on the reclaimed soil.

Apart of S-containing soils which consume plant-available nitrogen, we have obtained good growth of cereals, grasses, and legumes after with fertilizer applications of approximately 100, 40 and 50 lb per acre of N, P and K respectively. (The fertilizers used were ammonium nitrate, ammonium phosphate and potassium chloride.) In greenhouse experiments with four different reclaimed soils, plants showed no benefit from application of micronutrients (Fe, Mn, Cu, Zn, B and Mo).

The severe nitrogen deficiency in plants grown on heavily-limed soils containing unreacted elemental S was first found in field experiments, but was erratic in occurrence under field conditions. In a greenhouse test with four acidified soils (2 with little elemental S, and 2 high in elemental S), an application of 600 lb N/acre produced fairly good growth of barley on the soils for a six-week period immediately after liming. On a second cropping plants became severely nitrogen-deficient on the two soils high in elemental S, even though the equivalent of 300 lb per acre of fertilizer N was applied. Results for two of the soils are shown in Table 5. On an acidified soil with little elemental S a rate of 300 lb N per acre produced about as much growth as did 900 lb of N at each of four rates of lime application varying from 41 to 580 tons $CaCO_3$ per acre. (Table 5) However, on a soil initially containing 8.3% unreacted elemental S even 900 lb, N was not sufficient at the two highest rates of lime, as demonstrated by low yields (Table 5) and by plant symptoms of severe N-deficiency.

In a third cropping of the four heavily-limed acidified soils and a normal soil (Table 6), nitrogen treatments consisted of $NH_4NO_3$ at rates of 0, 300 and 1800 lb N per acre. A rate of 300 lb. N was sufficient on the normal soil and two acidified soils containing little elemental S (soils No. 1, 2 and 4 in Table 6). On the two acidified soils containing elemental S (soils No. 3 and No. 5 in Table 6) a rate of 300 lb N gave very poor growth, while 1800 lb. N produced high-yielding plants of normal appearance.

Our explanation of the high need for nitrogen after heavy application of lime to acidified soils containing elemental S is as follows. On addition of $CaCO_3$ soil pH is brought into a range (pH 7 to 8) suitable for activity of sulphur-oxidizing bacteria, and at the same time the $CaCO_3$ supplies the $CO_2$ needed by the autotrophic sulphur oxidizers. As the population builds up, nitrogen (and other

Table 5. Growth of barley (second cropping) with different rates of applied nitrogen on two acidified soils previously limed with different rates of $CaCO_3$.

| Treatment | | Acidified soil with 8.3% S[2] | | Acidified soil with 0.02% S[2] | |
|---|---|---|---|---|---|
| $CaCO_3$ (tons/acre) | Nitrogen[1] (lb N/acre) | Soil pH[3] | Barley yield (g/pot) | Soil pH[3] | Barley yield (g/pot) |
| 0 | 300 | 1.8 | 0.0 | 3.2 | 0.1 |
| | 900 | 1.8 | 0.0 | 3.0 | 0.0 |
| 41 | 300 | 2.4 | 1.3 | 7.1 | 3.7 |
| | 900 | 2.5 | 3.0 | 7.1 | 3.6 |
| 145 | 300 | 5.8 | 1.3 | 7.1 | 3.7 |
| | 900 | 5.7 | 3.0 | 7.1 | 3.6 |
| 290 | 0 | 6.8 | 0.3 | 7.4 | 1.7 |
| | 300 | 6.6 | 0.8 | 7.2 | 4.0 |
| | 900 | 6.5 | 2.1 | 7.2 | 4.4 |
| 580 | 300 | 6.8 | 0.3 | 7.1 | 4.1 |
| | 900 | 7.0 | 1.0 | 7.2 | 3.8 |

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[1] Applied as $NH_4NO_3$

[2] Elemental S content when soils were limed, which was 8 weeks before the start of the second cropping.

[3] Soil pH determined at the end of the second cropping, which was 15 weeks after time at which soils were limed.

nutrients) is tied up by the bacteria in their synthesis of protein. In addition there may be some denitrification of nitrate-nitrogen by one sulphur oxidizer, *Thiobacillus denitrificans*.

We have also found that in elemental S-containing soils which consume available nitrogen, phosphorus becomes deficient unless phosphorus is added together with the nitrogen fertilizer.

The rapid consumption of available nitrogen (and phosphorus) by heavily-limed S-containing soils has two practical implications. One is that the available soil nitrogen in reclaimed soils must be regularly monitored, and fertilizer applied as needed to avoid deficiencies which may be severe enough to prevent good establishment of plant growth. Massive doses of nitrogen fertilizers in a single application are not the answer, because they can produce a temporary condition of a salt content too high for plant growth. Instead, under field conditions, applications must be made at intervals as required, using rates of 100 to 200 lb N per acre. The other implication of our results is that treatment of heavy deposits of elemental S on soils by application of excess $CaCO_3$ plus nitrogen and phosphorus fertilizers may greatly increase the speed of oxidation of the S. The main end products of the oxidation would be $CaSO_4$ and $CaCO_3$, both of which are harmless in soils. Such a treatment may be preferable to physical removal of deposits, because wind-blown sulphur becomes mixed with soil and disposal of that reactive mixture is a problem.

### 4. Tolerance of different plant species to soil acidity

Plant species vary greatly in their degree of tolerance to soil acidity. The approximate minimum pH for good plant growth varies from pH 6.0 for alfalfa to pH 3.5 for aspen. (Table 7). Consequently, one of the effects of soil acidification is a shift in plant species to those that will tolerate low pH. In farm fields, areas of pH 4.0 to 4.5 will support no crops except oats, but usually have a thick cover of acidity-tolerant weeds (Canada thistle, quackgrass, etc.). In non-cultivated areas acidified to pH 4.0 to 4.5, grasses die out but aspen and some shrubs and weeds grow well.

Table 6. Effect of a heavy application of nitrogen on yields of third crop of barley grown on a normal soil and four acidified soils treated with heavy rates of $CaCO_3$.

| Soil | Elemental $S^2$ content (%) | Yield of barley plants (g/pot) with different rates of N on limed[1] soils<br>No N | <br>300 lb. N/acre | <br>1800 lb. N/acre |
|---|---|---|---|---|
| 1. Normal (pH 6.1)[2] | Nil | 0.9 | 5.1 | 6.1 |
| 2. Acid (pH 1.9) | 0.03 | - | 3.8 | 2.2 |
| 3. Acid (pH 1.4) | 29.1 | - | 0.2 | 4.3 |
| 4. Acid (pH 3.0) | 0.02 | 3.5 | 4.4 | 5.0 |
| 5. Acid (pH 1.4) | 8.3 | 0.3 | 2.2 | 7.8 |

[1] Rates of $CaCO_3$ applied to the different soils were 582, 509, 509, 209 and 209 tons/acre for soils No. 1 to 5, respectively.

[2] Elemental S content and pH of soils measured immediately before lime was applied 15 weeks before the start of the third cropping reported in this table.

Despite the tolerance of some species to very acid soils, planting of tolerant species is probably not a practical substitute for liming. Areas with soils in a pH range suitable for acidity-resistant species grade quickly into areas so acid that nothing will grow. In addition, areas that will support some resistant species produce acid run-off water.

Table 7. Estimated relative tolerance of some plant species to low soil pH.

| Common name | Generic name | Approximate minimum soil pH for good growth[1] |
|---|---|---|
| Alfalfa | *Medicago sativa* | 6.0 |
| Stinkweed | *Thlaspi arvense* | 5.8 |
| Barley | *Hordeum vulgare* | 5.3 |
| Red Clover | *Trifolium pratense* | 5.2 |
| Most cultivated and native grasses | - | 4.5 to 5.2 |
| Oats | *Avena sativa* | 4.8 |
| Wild Oats | *Avena fatua* | 4.5 |
| Quackgrass | *Agropyron repens* | 4.0 |
| Ladies Thumb | *Polygonum persicaria* | 4.0 |
| Spreading Dogbane | *Apocynum androsaemifolium* | 4.0 |
| Willow | *Salix sp.* | 4.0 |
| Wild Rose | *Rosa woodsii* | 3.5 |
| Saskatoon-berry | *Amelanchier alnifolia* | 3.5 |
| Aspen | *Populus tremuloides* | 3.0 to 3.5 |

[1] These values were established by field observation, except for the field crops where values have been determined experimentally. Values are only approximate, and will vary somewhat from soil to soil.

## 5. Practical difficulties in reclamation of sulphur-acidified soils

Reclamation by liming is fairly simple and inexpensive, provided soils are cultivated or under grassland, acidity is not too severe (pH not less than 3.5 to 4.0), acidity extends only to depth of 6 or 7 inches, and provided the soils are very low in unreacted elemental S. After determination of lime requirement (which may be as high as 10 to 15 tons $CaCO_3$ per acre), the application and incorporation of $CaCO_3$ and the subsequent fertilizing and sowing can be conducted using the same equipment and techniques employed on naturally-acid farm soils ( 4).

Reclamation becomes very costly and time-consuming, however, when soils are deeply and severely acidified and contain large amounts of elemental S, and especially when such soils are erodable or under tree cover. Reclamation then needs a great deal of attention to detail, if it is to be successful and permanent damage to soils avoided. The following is a list of things that can "go wrong" in practice on the reclamation of severely-acidified soils.

1. Use of strong alkalis, $Ca(OH)_2$, or ground limestone with too high a content of $MgCO_3$. The result will be a permanently saline soil (from formation of soluble sulphate salts) and/or a soil pH too high for plant growth.
2. Not applying enough $CaCO_3$ to counteract $H_2SO_4$ formed on the oxidation of elemental S remaining in the soil at time of liming. The amount of $CaCO_3$ needed to counteract elemental S may be as much as 10 times as great amount needed to neutralize the immediate acidity of the soil.
3. Use of ground limestone ($CaCO_3$) which is too coarsely ground. For rapid reaction ground limestone must be fine enough that at least half will pass a 60-mesh sieve. With coarse material reaction rate is so slow it may take years for the $CaCO_3$ to neutralize the $H_2SO_4$ in acidified soils.
4. Earth moving or bulldozing before reclamation which results in concentration of elemental S deposits.
5. Failure to work lime deeply enough into the soil (at least

6 inches) when immediate reclamation is wanted. It will take several years for surface applied lime to move downward enough to establish a neutral rooting zone in the soil.

6. Reclaiming of downslope or downwind areas first. Runoff water from untreated soil can re-acidify downslope reclaimed areas. In addition, sulphur deposits on untreated barren soils can be moved by wind or water erosion onto reclaimed soils and form a very acid surface layer which "burns off" newly-established plants.

7. Inappropriate soil sampling in determining extent of soil acidity or lime requirement of acidified soils. In slightly acidified non-cultivated areas the 0-to-2 inch soil depth may be acid enough to cause harm to grasses, but a 0-to-6 inch soil sample may be much less acid. In severely-acidified areas with unreacted elemental S, lime requirement can vary drastically over short distances. Soil sampling in such areas must be aimed at obtaining samples from those portions of the area with the highest lime requirement.

8. Insufficient nitrogen (and phosphorus) fertilizers to meet plant needs on reclaimed soils which are high in elemental S and which can rapidly immobilize nitrogen.

The errors listed have all been encountered either in field experiments or in field scale reclamation. They are detailed here to demonstrate the painstaking work needed for successful reclamation of sulphur-acidified soils.

## 6. Reclaiming acid waters

Experiments have been conducted with two conditions: a stream periodically made acid by run-off from adjacent areas of sulphur-acidified soils; and sloughs where both the water and slough-bottom soil were very acid and the bottom soil contained elemental S.

Lining the stream-bed with coarsely ground $CaCO_3$ (particles crushed to pass a ¼-inch sieve) did not neutralize water flowing in the stream. Fine particles of $CaCO_3$ were carried away with water, and coarser particles exposed too small a surface area for reaction with the acid water. Acidity of water in the stream was prevented only by liming most of the acid soils and acid sloughs from which the water originated.

The acid sloughs contained water high in sulphates and bottom soil was high in both sulphates and elemental S. It was feared that increased biological acitivity after liming of these very acid sloughs (pH 2 to 3), might result in production of objectionable amounts of $H_2S$. Consequently an experiment was conducted under artifical conditions with different treatments applied to slough soil and water kept in large containers. (The soil contained 1,200 ppm of water-soluble $SO_4$-S, 9.4% elemental S by weight, and had a pH of 2.4.) Treatments consisted of NaOH, $Ca(OH)_2$ and $CaCO_3$ applied through the water to the soil surface, and $CaCO_3$ mixed into the soil. During a subsequent two-month period there was no detectable $H_2S$ odor from water in any of the treatments. Water sampled at 6 weeks showed lower salt content and sulphate content in treatments receiving $CaCO_3$ rather than $Ca(OH)_2$ or NaOH (Table 8). Further, treatment with $CaCO_3$ produced water in the pH range of 7.6 to 7.8 whether the $CaCO_3$ was surface applied or mixed into the soil, and whether the $CaCO_3$ was added at a heavy rate or a lighter rate. In addition, trout fingerlings survived without apparent harm for a 5-day period in water from the $CaCO_3$ treatments.

On the basis of that experiment a number of acid sloughs were reclaimed by surface application of finely ground $CaCO_3$ at rates of 100 to 200 tons. Observations to date (less than a year after reclamation) show return of aquatic insects and algal growth to the previously barren sloughs, and the sloughs have not produced strong odors of $H_2S$. Not enough time has elapsed, however, to be sure that there will be no undersirable side-effects from reclamation of the acid sloughs.

Table 8. Effect of different treatments of slough water and slough-bottom soil on chemical composition water and survival of trout fingerlerings.

| Treatment |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Material | Rate (tons/acre) | Method of application | pH | E.C. (mmhos/cm) | $SO_4$-S (ppm) | Sulfide-S (ppm) | Trout survival at 6 weeks |
| None | - | - | 2.7 | 1.3 | 204 | 0.1 | * |
| NaOH | 3.7[1] | Surface | 9.8 | 5.3 | 285 | 0.0 | * |
| $Ca(OH)_2$ | 6.7[1] | Surface | 11.9 | 4.5 | 305 | 0.2 | * |
| $CaCO_3$ | 66.0 | Mixed | 7.6 | 0.8 | 98 | 0.0 | Yes |
| $CaCO_3$ | 9.1[2] | Surface | 7.7 | 0.7 | 120 | 0.1 | Yes |
| $CaCO_3$ | 66.0 | Surface | 7.8 | 0.8 | 119 | 0.0 | Yes |

* Not determined.

[1] These rates sufficient to neutralize immediate acidity of bottom soil.

[2] These rates sufficient to neutralize immediate acidity of soil, plus $H_2SO_4$ produced were elemental S content of the soil to oxidize.

## GENERAL DISCUSSION AND CONCLUSIONS

Windblown elemental S travels only short distances, but can cause very severe acidification of soils and waters within a period of only 2 or 3 years. Fortunately, even with soils and waters that have become so acid that they are completely barren, growth is quickly restored after application of massive doses of lime ($CaCO_3$). Our short-term field experiments have shown no harmful side effects from that type of reclamation. However, reclamation is expensive, with total costs of several thousand dollars per acre when very heavy rates of $CaCO_3$ (100 or 200 tons per acre) are needed. The practical difficulty with reclamation is that errors in any of a number of steps in the operation can cause either temporary or permanent failure for the reclamation.

## ACKNOWLEDGEMENTS

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# THE PROBLEM OF SOIL ACIDIFICATION BY SULPHUR DIOXIDE

by

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Approximately half a million tons of sulphur dioxide gas ($SO_2$) are emitted annually in Alberta, by gas processing plants and during extraction of oil from oil sands. The quantity emitted is likely to increase for at least the next twenty years as more oil sands plants come on stream.

Like elemental sulphur, $SO_2$ may be oxidized (either partially in the atmosphere or in the soil) to $H_2SO_4$, causing acidification of soils and waters where it is deposited. But unlike elemental S, which normally affects only a few acres local to its sources, $SO_2$ emitted into the atmosphere is dispersed over great distances and affects very large areas. Probably some millions of acres in Alberta receive significant deposition of $SO_2$ (Nyborg 1973, Baker et al 1973).

Increased acidity of rain and snow has been documented in Scandinavia (Anon. 1971), England (Likens 1972), the United States (Johnson et al 1972), and Canada (Walker 1969, Nyborg 1973, Baker et al 1973). But the quantities of sulphur dioxide brought down in precipitation, though significant, are far less (about one tenth) than the quantities deposited directly on soil or absorbed by surface water or vegetation (Nyborg 1973 and recent unpublished data). In forests, significant amounts may be adsorbed onto bark and foliage, to be washed into the soil by rainfall (Baker et al 1973 and recent unpublished data).

The rate of soil acidification by sulphur dioxide is probably relatively slow, but over many years (say twenty or so: the design basis for the life of a gas plant) may be sufficient to inhibit growth of acid-sensitive plants. We measured sulphur dioxide depression of soil pH near a gas treatment plant, to be in the order of 0.05 to 0.10 pH units over a period of 3 to 10 months. This could lead to depression of soil pH by 1 unit in about 10 years. A decrease of 1 unit in soil pH would mean that many farm soils in Alberta could no longer grow alfalfa and some could not produce high yields of barley (Hoyt et al 1974). In forests and natural grasslands, there would likely be shifts towards more acid-tolerant, possibly less productive, species.

Projections based on our preliminary results are, however, subject to wide margins of error. Accurate measurements of sulphur additions from $SO_2$ are difficult because the background level of native sulphur in soils and plants is high relative to the annual additions. The importance of different mechanisms of addition to soils has not been determined for Alberta conditions. Also, natural temporary shifts in soil pH occur with seasonal or yearly changes in biological activity.

But our projections are supported by calculations based on the rate of output of industrial $SO_2$. If we assume that sulphur from $SO_2$ is taken up by soils for only 6 months of the year when the land is free of snow cover, then approximately 250 million lb of S would be deposited each year in Alberta. That amount of S deposited on, say, 5 million acres would mean an average addition of 50 lb S per acre. That amount would generate 150 lb of sulphuric acid per acre. Considering the buffering capacity of Alberta soils, that would result in a drop in pH of 0.5 to 1.5 units in the top 6 inches of soil after a period of 10 or 15 years.

Such projections and calculations are further supported by field observations. The pH of soil surface organic matter appeared to be depressed by 1 to 2 pH units at distances of up to 16 miles from a gas processing plant that had been operating in a forestry area for about 15 years (Hocking 1974, unpublished data).

If $SO_2$ emissions acidify soil and water at the rates indicated by our preliminary work, some areas of the province may with time require "reclamation" to offset the effects of the increased acidity. Approximately 40% of the cultivated land in Alberta is naturally slightly acid with soil pH in the range of 5.5 to 6.5 (10), and for those soils a drop in pH of 0.5 to 1.0 units will definitely reduce yields of acidity-sensitive crops such as alfalfa and barley. However, "reclamation" of cultivated land would be simple and fairly inexpensive, consisting of application of agricultural lime ($CaCO_3$) at a rate of about one ton per acre. Reclamation would not be so simple or certain for forest land or surface water. Even if forested soils and bodies of water can be restored by surface application of lime (as suggested by our initial experiments), the cost of treatment may be very high.

The most important questions about the effect of $SO_2$ on soil and surface water are the following:

(1) What is the rate of sulphur deposition and rate of acidification in different agricultural and forest areas;

(2) How much sulphur deposition and acidification can be tolerated by forest soils and by water without harm to vegetation or aquatic life; and

(3) can forest land and bodies of water be restored, and at what cost?

Those questions should be dealt with immediately, because the cumulative effect of sulphur emissions on soil and water may persist long after the sulphur depositions have ceased.

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# SURFACE DISTURBANCE & RECLAMATION IN THE EXPLORATION PHASE

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CanPac Minerals Limited and its predecessor, The Mining Division of Canadian Pacific Oil & Gas, have conducted coal exploration programs in the Rocky Mountains since 1967. These programs have been carried out in several locations: the Upper Elk Valley of British Columbia, the headwaters of the Red Deer River, the Elbow River and the Oldman River. In all instances, the project locations were mountainous areas with exploration being conducted above the 5,000 foot level, and in many instances, above the treeline.

The primary objective of these coal exploration programs was the delineation of known coking coal reserves. This was accomplished by geological reconnaissance, test drilling of the more favourable areas, trenching of seam outcrops to establish continuity and the collection of large samples of unweathered coal for testing purposes.

Prior to any work being commenced in the field, CanPac submitted a detailed map to the Provincial Government showing the proposed campsites, road locations, drill sites, trenches and bulk sample sites for that particular exploration program, anticipated for a particular summer's work.

Reconnaissance was conducted by geologists; preliminary field mapping along with some trenching of the coal seam outcrops with hand tools pinpointed areas of interest for detailed exploration. Test drilling with Diamond Drills or Rotary Drills is usually the next step in gathering information about the coal quantity and quality. Access for drilling rigs requires construction of roads. These roads were initially laid out on topographic maps, using aerial photographs as a guide. This step was done for the submission of a detailed project map when permission was sought from the Provincial Government to undertake an exploration program. The actual route of an access road in the field was marked and approved by the local Forest Ranger prior to construction. All the roads built were kept to a minimum width, usually

16 feet across the crown of the road, or the width of a bulldozer blade. At no time were gradients above 15% exceeded, and normally the roads were confined to a 10% gradient.

The crossing of all water courses was initially accomplished with brush culverts. Siltation of these structures and their subsequent blockage led to widespread use of steel culverts. The road system established for the exploration program in the Oldman River watershed proved to be quite extensive - some 60 miles of road were built over a 4 year period; however, roads were devised to provide access to several drill sites and at the same time minimize disturbance of the surface. Where exploration access was required above the treeline, routes were selected to traverse areas of rock talus or scree slopes in deference to alpine meadows.

During the initial years of exploration, some roads were constructed along the exceptionally steep areas of the scarp face of some ridges. This practice was abandoned later when stability problems arose with the outslope shoulders of these roads. Now all roads are built on the dip slope side of the ridges.

Trenching of the coal seam outcrop is an excellent guide to coal seam thickness and continuity. This trenching was done with bulldozers; however, the coal bloom at the outcrop proved to be an eyesore when it was pushed aside to expose the unweathered coal. The bulldozer has been replaced by a different approach to coal seam trenching. Now a road is built immediately above the coal seam and a backhoe excavates trenches down to the coal seam, and in many instances trenches were excavated to sufficient depth to expose a full section of the coal seam. These backhoe trenches were immediately filled upon completion of mapping by geologists. Following the abandonment of the area the trenches and the access road were sown to grass.

Throughout last year's exploration program extensive grass seeding was undertaken on access road backslopes and outslopes. Several drill sites and their access roads were also reclaimed where the coal seams proved to be uneconomic. The adit sites, where tunnels were driven into the coal seam to gather large samples of non-oxidized coal, were cleaned up and sown to grass. In one instance the site was completely restored to the original contour. Prior to abandonment of the project for the winter, all berms were removed from the access roads and the roads were extensively cross-ditched to inhibit erosion.

The seeding of roads, drill sites, and bulk sample sites was carried out both in the later spring and early fall. Recent trips to these sites have indicated that seeding in the spring was the most successful, particularly along areas that were excavated or reclaimed just prior to seeding.

# HABITAT ENHANCEMENT IN A DISTURBED NORTHERN LANDSCAPE

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## ABSTRACT

Most of the recent disturbance studies in the Canadian north have focussed on the negative aspects of man-induced changes to the landscape, and rightly so. Because of this approach, one of the factors that has received little investigation is the potential for some disturbed sites to ultimately enhance habitat values for wildlife. Preliminary results of a study in the Yukon Territory suggest that under certain circumstances, the biological diversity of an alpine tundra environment may increase after a man-caused disturbance.

The Burwash Uplands study site is situated some 25 km west of Burwash Landing, Yukon Territory. This location provides an excellent opportunity to determine the long range effects of physical disturbance on the alpine tundra environment. During the late 1800's, a wagon road was established from Burwash Landing northwestward across the uplands to the Chisna and White River District gold fields, and it was intermittently in use until the 1930's. Today some 30 km of the road in the uplands is still evident although it has not been used for some 40 years. The road is particularly visible because the original vegetation along the trail has been replaced by a different plant cover.

The Burwash Uplands is a region of sedge (Carex spp. and Eriophorum spp.) tussock tundra underlain by high ice-content permafrost. The hypothesis currently being tested is that thermokarst degradation along the trail created moist depressions that were colonized by willow (Salix spp.) and some ground birch (Betula glandulosa). Secondary plant succession then led to an interesting interaction between the trail vegetation and caribou (Rangifer tarandus var. osborni); during early summer new terminal shoots of willow are preferred as

browse, and since willow is locally present only along the roadway, these animals follow it while feeding. As a result, concentrations of this caribou herd (numbering approximately 200 animals) along the trail maintain degradation so that the moist depressions remain, and normal plant succession which would enable the site to return ot its former vegetative cover is repressed.

The disclimax plant association along the trail exhibits greater species diversity and has a greater annual productivity than surrounding vegetation. In addition to use by caribou, microtines (especially *Microtus oeconomus* and *Clethrionomys rutilis*) and avifauna (*especially Lagopus lagopus*) concentrate along the trail and use the disclimax vegetation as a food source. The smaller mammals and birds also use the vegetation along the roadway as their primary cover habitat.

Preliminary results of this study thus strongly indicate that certain types of tundra disturbances may in time actually benefit wildlife. These findings, when complete, may be of particular interest to those engaged in habitat manipulation.

## *THE PLANTS INVOLVED AND THEIR SELECTION.*

# RATIONALE AND PROBLEMS IN THE USE OF NATIVE PIONEER SPECIES IN LAND RECLAMATION

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In assessing the rationale for land reclamation in the context of the Arctic Gas Pipeline project, I find it stems not from a desire to paint disturbed land green again but from the acceptance of a basic attitude of environmental protection. Removal of the protective plant cover, particularly in permafrost influenced terrain, often results in soil instability which represents the degradation of a portion of landscape. Such actions then threaten the habitat quality of terrestrial and aquatic life of the area. In order to properly understand the pipeline potential for disturbance, Canadian Arctic Gas has carried out extensive ecological research in Alaska, the northern Yukon, the Mackenzie Valley of the Northwest Territories, and more recently in Alberta. The total estimated sum of money spent on purely ecological research by the end of 1973 was $10 million, with about $1 million of that specifically for revegetation or related studies.

The basic objectives of our restoration studies have been: (1) to quickly provide a ground cover to control erosion and help restore the natural energy budget and (2) to restore the damaged ecosystem, as much as practicable, to a natural primary successional state.

I would like to propose the following definitions of two very commonly used terms. The first is revegetation, which I think of as quickly providing a plant cover for erosion control. To revegetate an area quickly, we generally use plant species not common to the disturbed area, certainly not common in the dense stands we are often able to establish. This serves an immediate short-term purpose. Reclamation, or to reclaim a natural area from a disturbance, requires that we restore the damaged ecosystem, as much as practicable, to a primary successional state which can only be accomplished by using the same species as would naturally invade, given sufficient time.

This paper deals primarily with the rationale and problems of achieving the second objective. However, as they both must be put together for a successful restoration program, I wish to briefly trace our approach, which started by satisfying the first objective.

Three years ago, we faced the task of developing a restoration program for a pipeline right-of-way which will traverse a multiplicity of habitat types over the expanse of 2600 miles. Conditions range from Arctic coastal tundra through the boreal zone of North America and across the prairies. Recently we've had the Cordilleran region of southwestern Alberta thrown in just to add a little interest and expand the challenge. In viewing this problem, it was decided that we required two types of information. The first was, what species and varieties of available plants could successfully establish and grow in arctic and subarctic regions? The other was, we required data on the conditions for plant growth over the full range of country through which the line will be constructed.

To answer the first question, plots were established at Norman Wells, Sans Sault, Inuvik, and Tuktoyaktuk in the Northwest Territories and at Prudhoe Bay in Alaska. This work was carried out by a number of consultants plus faculty members at the University of Alberta. The result of this experimental work was released to the public on March 21, 1974, along with our pipeline application of the Canadian and American governments.

To satisfy our needs with regard to the second very large objective, that of understanding the range of habitat conditions throughout the length of the pipeline, a systematic landscape survey was started in 1971. The pipeline route was broken into major physiographic regions for the purpose of organizing the studies in an orderly manner. The entire route was photographed, photo-strip-mosaics prepared, and landforms and engineering soil characteristics mapped. This terrain analysis formed the basis of our landscape-vegetation survey of representative areas between Prudhoe Bay and northern Alberta. In 1974, we will extend our survey through Alberta. Data collected included floristic composition, cover, landform, slope, aspect, elevation, soils (including profile development, texture, and nutrient status), and drainage. These data were then used in the formulation of a landscape classification which serves to organize the complex landscape into a manageable number of ecologically meaningful units.

By combining these two research programs, we have been able to develop a program of right-of-way revegetation in which we have a great deal of confidence.

To satisfy the second basicobjectiveof the project, or that of repairing the disturbed natural ecosystems, we must understand the process of natural succession. The maintenance in natural communities of small, but well-adapted populations of colonizing species is one of nature's ways of repairing ecological damange. It seems reasonable that one of the more ecologically suitable approaches to the repair of man-made disturbances would be to utilize the ecosystem's own repair system, i.e. naturalcolonizing species, in any attempts at reclamation. Because these species are a natural part of the established ecosystem and have a fitness to the environment in which they are found that is the result of thousands of years of selection, they are expected to form the basis of a long-term, low maintenance restoration program.

Though the rationale for utilizing native plant species in disturbed land reclamation is easy enough to define and explain, many problems must be solved before we realize a workable, practical program. Though the principles and approach would be the same for a project utilizing native species to solve a reclamation problem in the Fort McMurray area, at least one of the species would be different from the project I'm about to elaborate on. The value of our experience, however, should be helpful to anyone considering a similar project.

Studies in the Northwest Territories have demonstrated that certain commercial grass species can survive and provide good cover over a three to four year period. However, little or no information is available on their long-term success in these areas: i.e., how they will react to an unusual winter or summer, or attack by parasites and diseases common to arctic and subarctic regions.

Similar studies of two native pioneer grasses, Arctagrostis latifolia and Calamagrostis canadensis, have shown that, though they are slow to establish, their cover and biomass production by the end of the third growing season can equal or exceed that of most of the commercial varieties. Planted in Inuvik, N.W.T., in 1971 along with six promising agronomic varieties, the two native grasses grew very little the first year. By the second summer,however, four of the agronomic species had winter-killed, but both native grasses were vigorous and had substantially increased their growth. At the end of the summer of 1973, all species were clipped for biomass measurement. The native grasses were found to be the most successful species, having an annual production of two to eight times that of the two surviving agronomics, Arctared Creeping Red Fescue and Nugget Kentucky Bluegrass.

The first problem to be faced in a native seed increase project is the obtaining of seed stocks in adequate quantities to make field multiplication feasible. Seed of both species was collected, by hand, from late July to September 1973 along a latitudinal gradient between Fort Simpson and Tuktoyaktuk, N.W.T. We succeeded in collecting approximately 300 pounds of seed. Germination studies have shown the seed to be very viable, having germination percentage between 80% and 95%.

The second problem, once seed has been obtained, is the raising on an agricultural scale, species adapted to disturbed northern niches. To cultivate and increase the seed of these two native species for use in pipeline revegetation, it is necessary to determine:

1. The requirements for flowering and seed head production at lower latitudes.
2. The cultural practices required to maximize seed production.
3. The ecotypic varieties best suited to meet the needs of this project.

Studies in these areas will be accomplished in field plots at Peace River, Alberta; Tununuk Point, N.W.T.; in the Matinsuka Valley in Alaska; and in greenhouse facilities in Calgary.

For the purposes of this paper, I will briefly summarize the specific research topics covered by the project which we have or will have underway this year.

## A. Species Performance

The objectives of this program are to:

1. Determine how interspecific competition among species within a seed mix, sown at various rates, will affect the survival and establishment of the two native grasses, and
2. Compare root and shoot production of native and commercial grasses when grown at low soil temperatures.

## B. Ecotypic Variation Studies

Clones of both species were collected at a number of locations between 60° and 70°N latitude in 1973. These will be transplanted into common gardens at Peace River and Tununuk Point, N.W.T., this spring. Observations and measurements will be made to determine genetic variation and response to the environment in an attempt to identify varieties or traits desirable for future breeding and improvement programs.

## C. Seed Increase and Related Cultural Practices

Seed of both species will be planted in 20-to 40-acre plots at Peace River, Tununuk Point, and Palmer, Alaska. The plots at Peace River and Pålmer will be used to both increase the seed stock and to test the influence of fertilizer and irrigation treatments on flowering and seed production. The plots at Tununuk Point in the Mackenzie Delta will be solely for the purpose of seed multiplication.

## D. Flower Initiation Study

The first or exploratory research into the flowering response of Arctagrostis and Calamagrostis will be conducted using only those strains collected from Inuvik, N.W.T. The objective will be to identify those factors or combination of factors most important in the flowering response of these two species.

The following are the conditions identified as possible key factors in the successful flower induction of Arctic grasses:

1. Chemical Treatment: To determine the influence of soil fertility in hastening the development to the induction stage, various treatments of N, P and K will be tested. Gibberellins are under consideration,

though we're not certain they would be beneficial with flower initiation in grasses.

2. Pre-photoinductive Cold Treatment: All plants will receive a cool dark treatment of three weeks prior to any light treatment.
3. Photoinduction: During induction, plants will be subjected to either a 24-, 16-, or 12-hour photoperiod of three weeks.
4. Post-photoinductive Cold Treatment: After photoinduction, half of the plants will receive an additional cool dark treatment.

The present research is exploratory and is designed to test several combinations of key factors which may be responsible for flowering in Arctic grasses. Future work in the area includes the determination of:

1. The level of each factor which alone or in combination with other factors is most conducive to flower production.
2. What, if any, differences there are in the flowering requirements of strains collected from other latitudes.
3. Ways of shortening the ripeness-to-flowering time.
4. Treatments which will maximize seed production.

It is obvious that I have very briefly summarized some very complex research objectives, the details of which would take many hours to expand upon. The point to be made is that the realization of the practical utilization of native pioneer species in land reclamation has many obstacles yet to be overcome. We are, however, very optimistic that they can and will be overcome.

For the benefit of those people here interested only in land reclamation in Alberta, I would state that the lessons we are learning and the principles of scientific research contained within our project are applicable to your situation. I hope my summary of this work has been helpful in defining for you the rationale and problems for the practical use of native pioneer plant species in land reclamation.

## Acknowledgment

I wish to thank Mr. W.E. Younkin of Northern Engineering Services Company Limited of Calgary for his very important contributions to the development of this project.

# THE POTENTIAL OF TREMBLING ASPEN FOR RECLAMATION PLANTING IN ALBERTA: SOME TECHNIQUES OF PROPAGATION

T. F. Laidlaw

## Introduction

Some reasons why trembling aspen (*Populus tremuloides* MICHX). appears to have considerable potential for reclamation planting in this province are:

1. It shares with balsam poplar a very wide geographic distribution in Alberta. Locally adapted genotypes could be found within a short distance of most reclamation sites.
2. Aspen can reproduce vegetatively by suckering. This suggests that initial establishment densities need not be high in order to attain satisfactory eventual stocking of a site. Field observations suggest that aspen would have little difficulty in spreading by suckers through established cover plantings of grass and forbs.
3. Established aspen appears to have moderate drought tolerance - an important consideration in the reclamation of exposed upland sites.
4. Although natural aspen stands are normally associated with medium-to-heavy textured upland sites, it could probably be artificially established on many sandy sites as well.
5. The natural poplar community, though highly variable in species composition, tends to be floristically rich (4, 6, 7). It is suggested that the intial establishment of aspen on a site would be followed by the gradual invasion of many associated species, the result being a species-rich natural plant community. The understory of this community, and its spatial relationship to adjoining grass-forb-shrub communities could probably be manipulated to a type most suitable for commercial forestry, wildlife habitat, etc.

## Propagation of Trembling Aspen - Some Presently Available Techniques

### A. From Seed

Over the past three years I have been doing some elementary work on the technical aspects of growing aspen from seed.

During the 1973 season I raised approximately 4,000 aspen seedlings in the Alberta Research Council "peat sausage" plug. These seedlings will be planted on various reclamation sites in the spring of this year. First-year survival information will be available this fall.

I thank the Research Secretariat for a materials-purchasing grant and the Alberta Research Council for supplying custom-made peat sausages. The seedlings were raised in NAIT growth chamber facilities.

Propagation of trembling aspen from seed, under semi-controlled conditions, is not particularly difficult. The following techniques have been tested with success by myself and are recommended to others wishing to propagate aspen from seed.

#### a. Collection of Seed

The stems of trembling aspen are unisexual. The female stems normally bear catkins in the latter half of April, which contain mature seed from late May (Edmonton vicinity) to the middle of June. Small catkin-bearing twigs should be stripped from the tree just as the catkins are on the point of dehiscence. The catkins should be spread out to dry or stored loosely in well-ventilated containers. Drying of the catkins will result in eruption of the seed and associated "cotton" within a few days.

#### b. Extraction of Seed from Cotton

Under certain conditions it may be desirable to sow unopened catkins or cotton and seed directly on the reclamation site. Field observations suggest that the cotton may be valuable in providing a light-transparent mulch over the delicate seedlings.

However, if seed is to be stored for considerable periods, or seedlings are to be raised under controlled conditions for later transfer to the reclamation site, it may be desirable to remove the cotton.

Very efficient extraction can be achieved by means of a tumbling technique developed by Einspahr and Schlafke (2), employing standard nested soil sieves and a pneumatic hose.

A fair amount of seed may be percipitated simply by vibrating or shaking the mixture of cotton, seed, and empty catkins.

c. Seed Storage

Freshly collected aspen seed has a very high germination (95-100% in all seed tested by me). It has no dormancy-breaking requirement and will germinate within 48 hours or less of being moistened and exposed to light. Healthy seed turns a characteristic light pink colour within a few hours of being moistened.

Germination percentage drops very rapidly under natural conditions but seed stored according to Moss's (5) technique (in a dessicator, over $CaCl_2$ crystals, at a temperature near 0°C) maintains its germination and vigour virtually unimpaired for at least a year.

Seedlings can therefore be started at any time of the year (under controlled conditions).

d. Starting Seedlings Under Controlled Conditions

The seed of trembling aspen is very small and the seedling has little initial resilience to environmental stress.

Einspahr (3) describes a technique for the production of nursery grown bare root stock from seed.

On the basis of my experience in growing aspen in forestry containers I suggest the following:

i. The seed should be surface-grown on a sterile substrate. Finely shredded peat moss, fine sand and mixtures of the two make satisfactory seedbeds. The seedbed should be moist but not wet. Prior soaking of the seedbed with a mixture of Captan 50W and garden sulphur is recommended.

ii. High humidity conducive to good germination and establishment can be provided by intermittent very fine mist or enclosure of the seedbed by glass or polyethylene. Occasional light misting with Captan and sulphur discourages damping off and mildew.

iii. Aspen is shade-intolerant and requires relatively high light intensisties (about 3500 foot candles) for maximal photosynthesis (1). A high light intensity is desirable for initial seedling establishment provided that this can be attained without excessively high air and seedbed temperatures.

Seedlings at NAIT were germinated and grown at temperatures between 55° and 65°F (12.6 to 18.3°C) as suggested by Bate and Canvin (1).

B. Vegetative Propagation

Aspen can be propagated vegetatively by means of both root cuttings (8) and young herbaceous stem cuttings derived from root cuttings (9).

In marked contrast to the native P. balsamifera and the poplar cultivars employed in shelterbelt planting, it is very difficult to root hardwood cuttings of aspen.

It would be theoretically desirable, by means of the above techniques to artificially clone these genotypes which, by virtue of suckering rates, height growth, drought tolerance, etc. seem to be the most suitable for a particular reclamation site.

However (in contrast to the importance of breeding and cloning poplar for commercial utilization) the most efficient selection and cloning of aspen for reclamation purposes might well occur naturally on the reclamation site following planting to a wide variety of genetic material.

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# SPECIES SUITABILITY FOR SAND DUNE RECLAMATION AT LESSER SLAVE LAKE, ALBERTA [1]

by

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## ABSTRACT

Sand dunes were severely disturbed by recreational overuse and sand excavation for highway construction in the Lesser Slave Lake Provincial Park. A study, related to the reclamation of these sand dunes, indicates that Russian wild-rye, nordan wheatgrass, pubescent wheatgrass, Alberta fescue, fairway wheatgrass, perennial ryegrass and sainfoin were the most successful species in germinating and growing on the sand. From the plantings of woody species, saskatoons, *Artemisia* cuttings and willow pole cuttings gave good results.

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# RECLAMATION AFFORESTATION IN THE GREEN ZONE OF ALBERTA

by

J. Selner

Alberta Lands and Forests

In 1971 the Forest Land Use Branch of the Alberta Forest Service conducted, financed and developed a reclamation survey of all abandoned and newly-mined coal localities in the green zone. The survey described the topography, geology, soils, hydrology and vegetation of each locality.

Natural plant invasion helped to resolve questions of revegetation. Broad-leaved and coniferous tree species were dominant on many abandoned mine sites. Grasses and legumes were sometimes completely missing from the primary colonizers.

Because of this survey, reclamation research is now directed partly at reclamation by afforestation. Reclamation to grass only (so popular in the past) very often shows chlorosis owing to critical lack of nutrients in the soil, and is sometimes difficult at high elevation. Established grass covers are weak and are unable to always control erosion, and sometimes result in complete failure.

Natural invasion of spoil banks by vegetation is a complicated process involving vegetation, soil, climate, geologic parent material, relief, organisms present, time and other factors. While one spoil bank under optimal conditions may naturally revegetate in 20-30 years another may remain quite bare. While some spoil banks are being colonized only with trees, others are being colonized with native grasses, perennials and shrubs, and still others with all groups of vegetation.

Coniferous and broad-leaved trees are experimentally planted in different areas, elevations and exposures on reclamation research plots established by the Alberta Forest Service. Correct timing and proper planting routines, fast transportation of the seedlings and selection for basic ecological requirements can reduce the mortality of trees planted onto spoil banks and abandoned mines.

Among successful tree species, *Picea glauca* (Moench) Voss is the most tolerant conifer able to survive on overburden, while *Pinus contorta* Dougl. var *latifolia* Engelm. is the second best. Both native Alberta poplars (*Populus balsamifera* L. and *Populus tremuloides* Michx) and the British Columbia native *Populus trichocarpa* torr. and Gray are valuable for reclamation afforestation up to 4,500 - 5,000 feet, and require our full research attention. Planting of nurse crops can create favorable microsite conditions for better afforestation.

Reclamation afforestation is very difficult or even impossible on steep slopes of incorrectly engineered spoil piles. Research plots established at such critical sites are providing basic information for better land use management and regulation development.

Results of planting coniferous species in fifteen plots on spoil piles at Sterco, Lovett, and Coal Valley near Edson are surprisingly good.

83.4% of all planted evergreens survive vigorously

85.8% - lodgepole pine bare-root
92.6% - white spruce bare-root
71.8% - white spruce containers

7.4% of all planted evergreens died off

6.6% - lodgepole pine bare-root
3.0% - white spruce bare-root
12.6% - white spruce containers

2.8% of all planted evergreens are in serious condition and will die probably in the near future

2.8% - lodgepole pine bare-root
0.6% - white spruce bare-root
5.0% - white spruce containers

6.4% of all planted evergreens are doubtful with the possibility of either surviving or dying in the near future

4.8% - lodgepole pine
3.8% - white spruce bare-root
10.6% - white spruce containers

Research afforestation in the Crowsnest areas is, predictably, less successful. Very low rainfall this summer caused results to be less successful than could be expected during other, more favourable years. The results obtained with coniferous species in 31 different research plots on the spoil pile areas at Tent Mountain and Grassy Mountain are as follows:

57.1% of all planted coniferous survived in the Crowsnest area vigorously:

54.9% - lodgepole pine bare-root
70.1% - white spruce bare-root
46.4% - white spruce containers

35.3% of all planted evergreens died off

38.5% - lodgepole pine bare-root
22.1% - white spruce bare-root
45.3% - white spruce containers

3.6% of all planted evergreen are in serious condition and will die probably in the near future.

2.6% - lodgepole pine bare-root
4.7% - white spruce bare-root
3.4% - white spruce containers

4.0% of all planted evergreens are doubtful with the possibility of either surviving or dying in the near future

4.0% - lodgepole pine bare-root
3.1% - white spruce bare-root
4.9% - white spruce containers

This averaged data obtained in the Crowsnest Forest was evaluated separately for the Tent Mountain area and separately for the Grassy Mountain area to determine differences between the more favourable Tent Mountain microclimate and less favourable Grassy Mountain microclimate. This evaluation is as follows:

| | TENT MOUNTAIN % | GRASSY MOUNTAIN % |
|---|---|---|
| Mortality | | |
| lodgepole pine bare-root | 25.0 | 41.9 |
| white spruce bare-root | 10.5 | 24.7 |

| | | |
|---|---|---|
| white spruce containers | 23.5 | 51.6 |
| evergreens average | 19.7 | 39.4 |
| Serious Condition | | |
| lodgepole pine bare-root | 4.0 | 2.2 |
| white spruce bare-root | 0 | 5.8 |
| white spruce containers | 3.5 | 3.4 |
| evergreens average | 2.5 | 3.8 |
| Doubtful Growth | | |
| lodgepole pine bare-root | 3.5 | 4.1 |
| white spruce bare-root | 0 | 3.7 |
| white spruce containers | 1.0 | 6.0 |
| evergreens average | 1.5 | 4.6 |
| Survived Well | | |
| lodgepole pine bare-root | 67.5 | 51.8 |
| white spruce bare-root | 89.5 | 65.8 |
| white spruce containers | 72.0 | 39.0 |
| evergreens average | 76.3 | 52.2 |

Differences in survival of the trees planted on spoil piles under very similar conditions confirm that ecological factors should be considered as a complex factor different for each reclamation site. Each site has its unique micro-environment which can react negatively or positively during reclamation development as proved on the Alberta Forest Service reclamation research plots.

# ESTABLISHMENT AND SURVIVAL OF GROUND COVER VEGETATION

H. Vaartnou

Alberta Department of Agriculture

Abstract - Phase I:

During the summer of 1973 a vegetation survey was conducted on disturbed non-cultivated sites in Alberta, including 165 roadside sites, 90 sites along powerline rights-of-way, 70 sites along pipeline rights-of-way, the White Wood Coal mine at Wabamun, and 25 sites in the oil sands area around Fort McMurray. The purpose of this survey was to characterize the vegetation on these sites and to pick out those species most likely to be useful in revegetation projects.

Two soil samples were taken from each site and brought into the laboratory for determination of pH, conductivity, sulfate, organic matter, free lime, texture, sodium, potassium and phosphorus. The correlations between soil properties and vegetation were examined. The seeds of approximately 50 species were collected for later use in growth chamber testing on oil sands tailings and for field test plots on disturbed rights-of-way.

Detailed reports are available.

Planned Objectives - Phase 2 (1974/75 and 1975/76):

(a) To select useful ecotypes and study the establishment and survival of proposed ground cover plantings.

(b) To study the production of seed.

(c) To study preparation of seed beds, seeding methods and early management of plants.

(d) To provide the preliminary recommendations (1976) for revegetation for reclamation purpose.

(e) To study the control of undesirable vegetation.

Proposed Methods:

The study is based on ecological genetics, utilizing the great natural selection pressure to help select ecotypes for reclamation.

Work co-ordinated by Department of Agriculture:

A. Environments for testing varieties and ecotypes.

In co-operation with Department of Highways.

1. Grey wooded, mixed wood forest
2. Peace River Parkland
3. Central Parkland
4. Foothills
5. Fescue grassland
6. Black solonetzic soil
7. Mixed prairie grassland
8. Brown solonetzic soil
9. Saline soil

In co-operation with Oil Companies and Department of Environment.

10. Fort McMurray - oil sands - waste dumps
11. Fort McMurray - tailing sand
12. Fort McMurray - tailing sand and peat

In co-operation with Department of Lands and Forests and Department of Environment.

13. Coal mines - south
14. Coal mines - west - central
15. Coal mines - high elevation

Other special sites to be tested, include air polluted and soil polluted sites, five sites on provincial parks and three disturbed wildlife ranges.

At each location 20 grasses and 5 legumes will be tested.

Varieties of *Festuca ovina*, *Festuca rubra*, *Poa pratensis*, *Poa compressa*, *Agrostis gigantea*, *Agropyron cristatum*, *Agropyron trachycaulum* and *Phleum pratense* will be used as cover crop mixture.

Two mixtures, each of 10 species, will be tested at each location.

All agronomic characteristics important to reclamation purposes will be recorded. Special notes on disease resistance will be taken. Notes on possible seed production at Fort Vermilion, Edmonton and Lethbridge will be taken.

Soil samples will be taken from each site, analysed and related to the local plant communities.

Climatic data for each site will be assembled and related to the local plant communities.

B. Growth chamber and greenhouse studies will be carried out in 1974, 1975 and early in 1976 with selected ecotypes.

C. Germination and early management tests will be carried out with native shrubs.

D. Tests to control undesirable vegetation will be carried out.

E. Native and naturalized plants will be tested on soils saturated with crude oil.

# *RECLAMATION OF OIL SPILLS*

# EFFECT OF LIGHT OIL SPILLS ON CROP GROWTH

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Department of Soil Science
University of Alberta

In response to continuing enquiries about damage to soils resulting from oil spills the Department began greenhouse and field plot studies in 1968.

A paraffinic crude oil, containing little $H_2S$ and scrubbed of most of the water, bottom sediments and NaCl was used in the testing program. In the greenhouse the oil was added and thoroughly mixed with each of four soils: a Grey Wooded (or Luvisolic) soil from Breton; a Black Chernozem from Ellerslie; a loamy sand; and a sub-soil clay at rates up to 3% by weight. Creeping red fescue was seeded and grown for over a year with several cuttings. While having an initial harmful effect on germination and growth, the lighter rates were not fatal and after a year growth was near normal.

In the field, experiments were laid out at the Breton Plots on a Luvisolic soil and at the Ellerslie Research Station on a Chernozemic soil. The design of the plots is shown in Figure 1 for a single replicate. Oil was applied in August, 1968, being broadcast on an established hay stand for the uncultivated plots, and on summerfallowed soil for the cultivated plots.

Each spring thereafter the cultivated plots were rototilled and then rows of common crops seeded at right angles to the oiled strips: Wheat, oats, barley, rapeseed, flax, brome, fescue, alfalfa, altaswede and sweet clover were used. Only germination and vegetative growth were observed.

Results were as follows:

(a) On the Luvisolic soil at Breton.

In July 1971, three years after the oil had been applied to the uncultivated plots, regrowth was rated thus:

Control - hay stand taken as 100% cover

1/3% oil - hay stand estimated at 98% cover

2/3% oil - hay stand estimated at 90% cover

1% oil - hay stand estimated at 73% cover

1 1/3% oil - hay stand estimated at 65% cover

2% oil - hay stand estimated at 52% cover

In 1972, fescue, brome and alfalfa were broadcast and raked into the surface. By the fall of 1973 evidence of the oil treatments had pretty well disappeared. Note that no effort was made to speed up the reclamation process. No fertilizers were used.

On the cultivated plots the effects of the lighter treatments disappeared very quickly. At no time did germination of wheat and oats suffer though their subsequent growth was poor in the first few years on the higher rates. Of all the crops tested rapeseed appeared to be the most sensitive, with barley and flax next. Germination of the grasses and legumes was difficult to assess because of perennial spotty stands. Even in 1972 rapeseed germination was still nil on the 2% plots. Again, except for the cultivation, no attempt was made to speed up reclamation.

Dandelion appeared to be the most resistant weed and a few plants soon became established in even the 2% treatment.

(b) On the Chernozemic Soil at Ellerslie.

The detrimental effects on the hay stand were less marked here than at Breton and recovery was faster. Canada Thistle quickly became established on all plots, regardless of oil treatment.

Effects on germination of crops were also less marked than at Breton. Here too barley, rapeseed and flax appeared to be most sensitive.

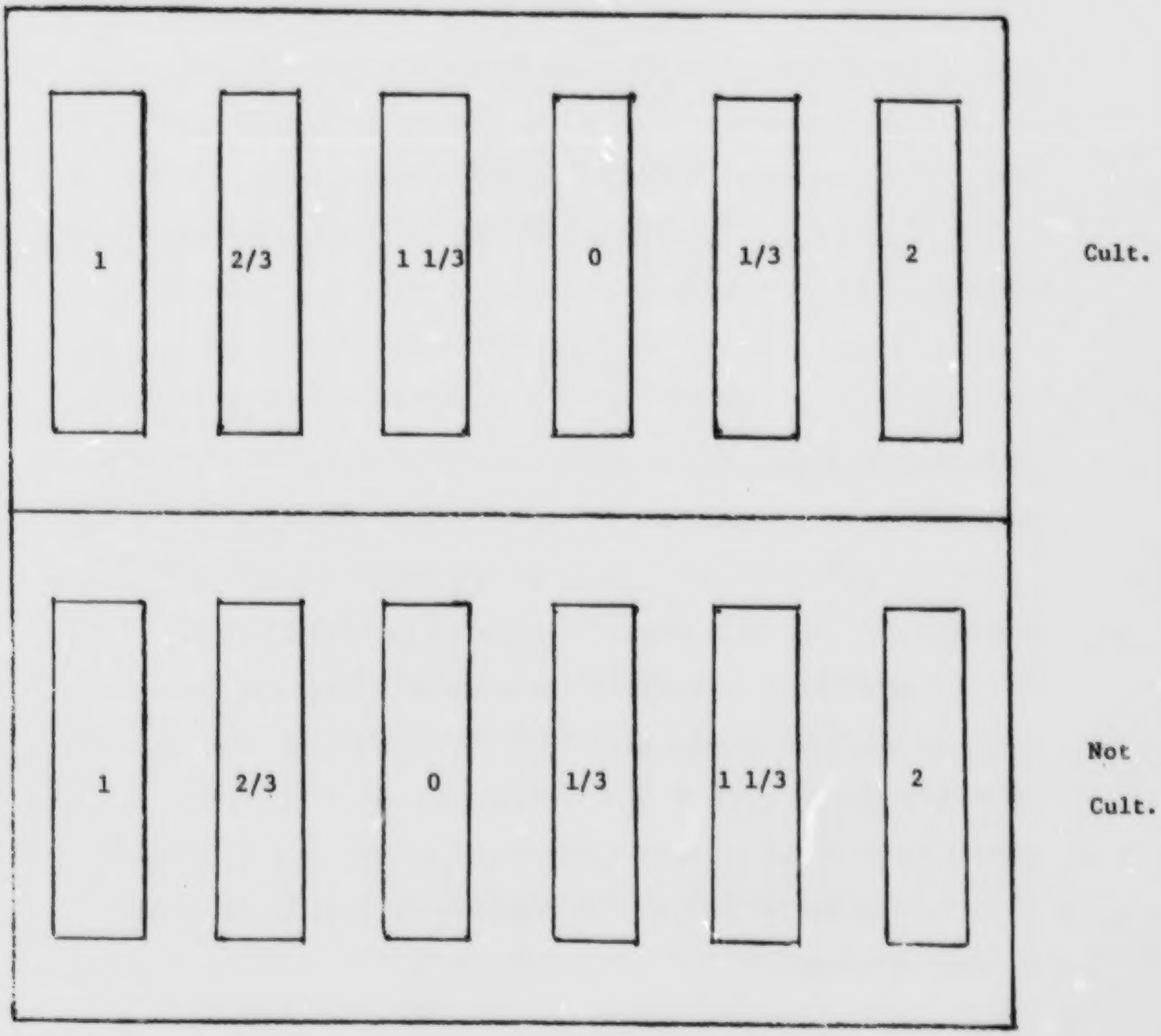
The study shows that light oil spills, although causing apparent immediate damage, need not be a cause for alarm. Even with no attempts to accelerate reclamation the soils will soon recover. Seeding of crops such as rapeseed, barley, or flax, which appear to be quite sensitive, should be avoided.

(Slides presented showing some of the points mentioned.)

The Department is now engaged in a major research project studying ways and means of speeding up the reclamation of agricultural soils damaged by oil spills at much heavier rates.

Figure 1. Detail of Replicate #2

Breton Plots


1
2/3
1 1/3
0
1/3
2
Cult.
1
2/3
0
1/3
1 1/3
2
Not Cult.

Plot size: 5' x 20'

Oil applied August/68

Rates: % on weight basis to plow depth.

# EFFECTS OF OIL SPILLS ON SOIL MICRO-ORGANISMS

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and

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## ABSTRACT

Field and laboratory investigations revealed that increases in soil respiration and bacterial numbers occurred in Arctic crude oil-inundated soils as compared with untreated control soils. A viable fungal component of the soil was found in oil-treated soils. Gas-liquid chromatography confirmed that crude oil was being decomposed in these Arctic soils but that the rates were slow as compared with temperate regions. Fertilizer greatly enhanced the rates of decomposition of oil. A wide range of micro-organisms were capable of degrading the n-paraffins present in crude petroleum.

# INTRODUCTION

The increased intensity of crude oil exploration and discovery in the Canadian Arctic during recent years has led to widespread interest concerning development, ecology and environmental protection in the north. Irrespective of stringent regulations and precautions, there is a likelihood of oil spills onto terrestrial ecosystems.

The ability of micro-organisms to decompose petroleum hydrocarbons in soils has been studied extensively since the early 1900's, mostly in temperate regions. The study herein reported was initiated in 1970 in an attempt to evaluate the effects of crude oil spillage on the microbial populations of northern permafrost soils.

The overall aims and objectives of this study were:

1) to assess the effect of crude oil on soil microbiological activity and biomass with reference to environmental factors such as temperature and moisture,
2) to examine the rates of microbial decomposition of crude oil in Arctic soils,
3) to examine means by which rates of microbial decomposition of crude oil in these soils can be enhanced, and
4) to examine taxonomically the indigenous populations of soil micro-organisms capable of utilizing crude oil as a carbon source.

## MATERIALS AND METHODS

### Field Studies

Two sites in the Mackenzie River Delta were selected for experimental oil spill plots. One site was located at Tununuk Point on the southern tip of Richards Island and the other at Tuktoyaktuk, representing distinct landscape units with respect to vegetation, topography and soil moisture (Table 1).

At chosen intervals of time, crude oil from Norman Wells, N.W.T. was applied to the surface of duplicate 3 x 3 m experimental plots, at both study sites. The amount of oil spilled was varied according to the thickness of the active layer at the time of application.

Soil from both untreated and oil-inundated plots was sampled over a three year period. Replicate core samples were removed intact using aluminum sampling tubes (45 cm x 6 cm) which were driven down to the level of permafrost. Thickness of the active layer was determined and soil temperature was recorded down the soil profile. The soil samples were wrapped in aluminum foil, sealed in plastic bags and immediately frozen.

To accelerate indigenous rates of microbial decomposition of crude oil, fertilizer ($NH_4$ $NO_3$ and $Na_3PO_4$) was applied onto selected oil-inundated plots at the rate of 200 kg/ha.

### Laboratory Studies

Initial analyses of field samples showed that only by combining studie of a general soil microbiological nature together with chemical analytical techniques could an accurate assessment of crude oil decomposition by micro-organisms be obtained i.e. population activity and substrate dis-

TABLE 1

Site Characteristics

| Site | Plant Community | Topography | Mean % Soil Moisture ($H_2O$/ovendry wt) July | Mean % Soil Organic Matter (loss on ignition) |
|---|---|---|---|---|
| Tuktoyaktuk | *Salix* heath/mosses & shrub/lichens | raised plain, hummocky | 261 | 76 |
| Tununuk | *Eriophorum*-/mosses & *Carex* tussocks/lichens | depressed area, low-centre polygons | 305 | 74 |

appearance.

Total numbers of bacteria and soil microbial activity were determined on both a seasonal and spatial basis on soil samples from oil-treated and untreated plots from both study sites. Soil dilution plates were used to estimate the number of viable bacteria per gram of soil. Total lengths of fungal mycelium were measured by direct observation using the agar-film technique of Jones and Mollison (1948). Oxygen uptake was measured in a Gilson differential respirometer fitted with large (250 ml) flasks described by Parkinson and Coups (1963). Recordings of soil respiration were taken successively at 0°C, 10°C and 20°C.

An extremely reliable method of determining microbial activity in soils is to assess the rate of substrate disappearance. Therefore, upon completion of the microbiological analyses of the soil samples, the residual crude oil was extracted from these same samples using soxhlet extractors and analyzed by gas-liquid chromatography. A Hewlett Packard (Model 5700A) gas-liquid chromatograph, equipped with dual-flame ionization detectors and fitted with a 24 ft., 1/8 in. stainless steel column packed with UC-W98 High Performance, was used for the analyses. The operational conditions were: injection port 250°C, detector 250°C, carrier flow ($N_2$) 30 ml/min, hydrogen flow 30 ml/min, air flow 240 ml/min, injection volume 2 ul, chart speed 1/2 in/min, range 100, attenuation 8. The oven was temperature programmed from 70-270°C at a rate of 8°/min.

In addition to those soils treated in the field, various experiments on selected soil samples were conducted under defined laboratory conditions.

One such study concerned the response by the soil microflora to various types of crdue oil, both with and without fertilizer amendments. Crude oil from Norman Wells, Prudhoe Bay and Atkinson Point was applied to seived soils from Tuktoyaktuk. One-half of each oil-treated soil received an application of N and P fertilizer. Following a 24 hour period of equilibration, respirometric measurements of replicate samples were taken at 15 C over a 36 day incubation period. Subsequently, the residual crude oil from each sample was extracted and analyzed by GLC.

A further phase of the research was designed to provide information concerning qualitative assessments of Arctic soil micro-organisms, in non-oil inundated soils and the effect of crude oil on these populations. Bacterial isolates were randomly selected from dilution plates and Warcup's (1950) soil plate technique was employed for the qualitative assessment of soil fungi. The length of time since oil application to the soils varied from 0 to 22 months.

## RESULTS AND DISCUSSION

The results of the biomass determinations were, in general, similar to those obtained in more temperate regions (Plice, 1948; Ellis and Adams, 1961; Foster, 1962; Schwendinger, 1968; McCown *et al.*, 1971; Odu, 1972). For the 0-5 cm section of the soil profile, bacterial numbers increased in oil-treated soils as compared with control soils (Table 2). For those soils treated in June, there was an initial decline in numbers in response to the crude oil. Subsequently, there were marked increases in the bacterial populations, indicating that a period of adaptation by

TABLE 2 Number of bacteria at Tununuk Point at three sampling times during 1971 (June, July and August) for both control and oil-treated soils. The number of months shown for the oil-treated samples indicate the length of time since crude oil was applied to the soil.

Number of bacteria/ g dry wt soil X $10^6$ for the 0-5 cm section of soil profile

| | June | | | July | | | August | | |
|---|---|---|---|---|---|---|---|---|---|
| Incubation Temperature | Control | Oil-treated | | Control | Oil-treated | | Control | Oil-treated | |
| | | 0 mo | 11 m0 | | 0 mo | 13 mo | | 0 mo | 14 mo |
| $0^{o}$C | 6 | 3 | 21 | .4 | .1 | .3 | 1 | 29 | 18 |
| $10^{o}$C | 17 | 10 | 180 | 12 | 9 | 274 | 12 | 312 | 312 |
| $20^{o}$C | 339 | 58 | 1065 | 18 | 28 | 311 | 37 | 550 | 509 |

TABLE 3 Soil respiration ($\mu$l $O_2$ consumed/10 g dry soil/6 hr) for the 0-5 cm section of the soil profile at Tununuk Point.

| Incubation Temperature ($^{o}$C) | Length of Time Since Oil Spillage (mo) | | | |
|---|---|---|---|---|
| | Control | 0 | 10 | 11 |
| 0 | 77 | 29 | 19 | 10 |
| 10 | 120 | 191 | 198 | 185 |
| 20 | 250 | 475 | 355 | 365 |

Three sets of samples were taken during 1971. The figures represent the mean of three replicate samples.

the hydrocarbon-utilizing bacteria was required. Those soils treated in July and August did not demonstrate a lag phase, suggesting that some bacteria were capable of utilizing hydrocarbons without requiring a detectable period of adaptation. The highest numbers of bacteria were recorded for those samples incubated at 20°C.

Soil respiratory rates were higher in oil-treated soils than in untreated soils (Table 3). The lower respiration at 0°C in the oil-treated soil suggests that the psychrophilic and mesophilic segments of the microbial populations react differently to crude oil.

Following oil treatment, the estimated total lengths of fungal mycelium decreased from 3200 ± 25 m/g dry wt. soil to 1600 + 100 m/g dry wt. of soil. However, 15 months after oil application, the fungal biomass recovered to the original amounts (Gossen, 1973).

The geochemical analyses showed that during the time interval allowed (14 months), decomposition of oil was not advanced in any of the above samples. However the entire range of n-paraffins disappeared after 34 months (Gossen, 1973). Fertilizer greatly increased the rates of decomposition of n-paraffins in oil (Table 4).

Significantly higher rates of respiration were recorded over a 36 day period in fertilized soils inundated with oil from both Norman Wells and Prudhoe Bay, in comparison with non-fertilized oil-inundated soils (Gossen, 1973). However, there was no significant difference between the fertilized and non-fertilized soils inundated with oil from Atkinson Point; attributable to the distinct lack of n-paraffins in the Atkinson Point crude (Gossen, 1973). Chromatograms of residual crude oil from these

TABLE 4 Degradation of n-paraffins in soil at Tununuk Point (3 replicate soil core samples).

| Treatment | Length of Time Since Spillage (mo) | $nC_{17}$:pristane |  |  | $nC_{18}$:phytane |  |  |
|---|---|---|---|---|---|---|---|
|  |  | 1 | 2 | 3 | 1 | 2 | 3 |
| oil | 1 | .86 | .86 | .84 | .99 | .94 | .96 |
|  | 2 | .82 | .81 | .80 | .98 | .92 | .96 |
| oil plus fertilizer | 1 | .68 | .82 | .81 | .77 | .93 | .91 |
|  | 2 | .34 | .31 | .54 | .38 | .36 | .39 |
| non-degraded test crude oil |  |  | .84 |  |  | .96 |  |

The ratios of normal paraffins to branched paraffins were established as indices of microbial degradation of n-paraffins. These ratios may be altered slightly by variations in chromatographic resolution, thus changes in the ratios of .05 or less were considered insignificant.

soil samples confirmed the more rapid rates of decomposition of n-paraffins in the fertilized Norman Wells and Prudhoe Bay crude oil inundated soils as compared with non-fertilized oil-inundated soils (Gossen, 1973).

Crude oil did not appear to significantly disrupt the species composition of micro-organisms qualitatively. However, minor changes in the populations occurred indicating the varying responses by the microbial populations toward the crude oil. Certain organisms appeared to be more prolific than others, in pure culture, with respect to their ability of degrading the n-paraffins present in crude oil. These organisms included members of the following genera: *Achromobacter, Streptomyces, Corynebacterium, Pseudomonas,* Gram positive cocci, *Micrococcus, Bacillus, Flavobacterium, Cytophaga, Penicillium, Paecilomyces, Verticillium and Mortierella.* Whereas all oil-decomposing fungi utilized the entire range of n-paraffins, many of the oil degrading bacteria appeared to be more selective in the range of n-paraffins attached. However, more species of bacteria than fungi were capable of metabolizing crude oil (Gossen, 1973).

Restricted sampling makes it impossible to draw detailed conclusions regarding changes in microbial populations caused by the introduction of crude oil. The choice of isolation method (i.e. soil plates) does not allow any inferences on the activity of the organisms isolated, particularly with the fungi. Thus the increased recording of such genera as *Paecilomyces* and *Penicillium* in soil following oil treatment might be due to high sporulation capacity and not their ability to maintain metabolic activity under conditions of oil inundation. However, the observation that *Paecilomyces* and *Penicillium* were potentially efficient oil degraders may suggest that these species are indeed present in an active form. More critical isolation methods and more intensive sampling programs are essential if any meaningful ecological data are to be obtained on the effects of oil spillage on fungal populations.

Similar comments could be made regarding the effects of oil spillage on bacterial ecology, but the problem here is compounded by the great range of physiological types of this group of the soil microflora. A study of specific biochemical types of bacteria which are important in nutrient cycling and organic matter degradation will be necessary to relate the interaction of oil spillage, bacterial activities and primary production.

In conclusion, the results of this study indicated that the most effectual means of reclaiming Arctic soil inundated with crude oil is to apply fertilizer and allow natural processes of decomposition to proceed.

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# METHODS OF ACCELERATING OIL DECOMPOSITION IN SOIL

by

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Plant growth is reduced by the presence of oil in soil. Part of this is due to nutritional effects caused by oil breakdown, part is due to poor aeration and poor wettability of soil containing large amounts of hydrophobic material; toxicity is also a factor. Effective reclamation of an oil spill site requires reduction of the quantity of oil present.

The oil content of soil can be reduced by burning, volatilization, biological decomposition and by leaching out of breakdown products. Burning is effective to varying degrees depending on the type of spill, the time between the spill and burning and soil conditions. Volatilization removes only the light fractions which account for very little of the oil after burning. Biological oxidation is the main disposal mechanism remaining. During this process, oil provides a source of carbon and energy (Fig. 1). In the presence of an adequate supply of mineral nutrients (especially N) and suitable environmental conditions (near neutral pH, conductivity <2.0 mmho/cm and adequate aeration and moisture supply) a large build-up in the amount of microbial material in soil results. Part of the C in the oil is respired as $CO_2$, and part is converted to microbial material. Growth and death of succeeding populations of soil organisms recycle the N incorporated into them and eventually utilize most of the energy available in the oil; some is retained in the form of soil humus. Eventually the added fertilizers are released and can be used for plant production.

Laboratory and field studies generally support the above theoretical description. The effectiveness of the treatments used to accelerate oil breakdown in soil can be assessed by four main techniques:

(a) Counting the number of microorganisms in soil. We have found that the number of microorganisms increases after an oil spill. The size of the population increases even further after addition of nutrients and aeration (Table 1). The balance between bacteria and fungi can be shifted by altering soil pH. Bacteria compete more effectively with fungi for available nutrients at a neutral pH. Thus, by adding lime to an acid soil (Table 1) the number of bacteria were increased at the expense of fungi. Although some fungi appear to have the ability to degrade crude oil, bacteria are generally considered more effective. Thus, the ability to shift soil conditions to favor bacteria is very important.

(b) Measuring the production of $CO_2$. This is a sensitive technique, is inexpensive and can be done in the field. The only problem is that one can not prove that all the $CO_2$ collected came from the decomposition of oil. The technique is useful though where a control unoiled portion of the same oil is available. It is also useful for comparing various treatments on the same oil-contaminated soil (Fig. 2 and 3). The $CO_2$ production rate is initially depressed by the presence of oil but gradually oiled soil achieves a more rapid respiration rate than its unoiled counterpart. Addition of nutrients increases the respiration rate by a factor of from 5- to 10-fold (Fig. 2 and 3).

(c) Monitoring the available nutrient status. This technique is useful in managing the nutrient regime of a soil to ensure the most rapid possible breakdown rate of the oil. The problem with it is that it does not relate directly to oil content. It has a sound biological basis and is essential to any program of reclamation following an oil spill on soil.

(d) Measurement of the residual oil content of soil. This direct approach is always desirable and provides sound information on the progress of oil decomposition. All of our studies use this together with techniques a, b, and c to access the progress and effectiveness of various reclamation procedures.

## GREENHOUSE AND LABORATORY STUDIES

Using greenhouse and laboratory studies, the effectiveness of treatments such as various forms of N, use of a detergent, liming or not liming, drainage and of having a crop or no crop on the soil has been examined.

The form of N added influences plant growth (see Nyborg, McGill, Carlson and Holland in this proceedings) and also appears to affect oil decomposition (Tables 2 and 3). On three Black Chernozemic soils studied, $NO_3$-N appears to be more effective in promoting oil breakdown than urea or ammonium-N. The reasons for this are not yet clear but it may be due to the plant-microorganism competition for N, to side effects of the form in which the N is applied (acidity salinity), or to the use of $NO_3^-$-N as a terminal electron acceptor and an increase in soil redox potential resulting from the $NO_3^-$. There appears to be no benefit of $NO_3^-$-N over $NH_4^+$-N in the organic (Leedale) soil studied (Table 3).

Various amendments such as detergents, lime and manure have been proposed as aids in accelerating oil decomposition in soil. Results of our studies indicate that the detergent used (Polycomplex A-11) has no beneficial effect on oil decomposition in either mineral soils (Table 2) or organic soils (Table 4). It is also of no value in promoting plant growth on these soils (see Nyborg *et al*. in this proceedings). Lime is useful in maintaining a neutral soil pH in the presence of high applications of ammoniacal N. Oil decomposition, however, is not markedly improved by its use (Table 2) on the Ellerslie and Redwater soils; similar results have been obtained with soil from the Morinville spill. Manure did have a slight beneficial effect on oil decomposition in the Morinville soil during the first cropping but this was not as obvious during the second cropping period (data not shown).

Results of studies to date indicate that added P is necessary for optimum oil decomposition but S is not. Soil from the Leedale spill (organic soil) near Rimbey was incubated with and without added P or S. With added P (and NKS) 78 percent of the original oil remained after 6 weeks whereas 84 percent was left in treatments receiving all nutrients except P. With no added nutrients, 90 percent of the oil remained after 6 weeks. No effect of S was observed. Different results may, however, be obtained with different soils, oils or incubation conditions.

The apparent advantage of $NO_3$-N in some cases may be caused by the cation associated with the $NO_3$. To test this hypothesis, various $NO_3$ sources were added ($Ca(NO_3)_2$, $KNO_3$ and $HNO_3$) to the Leedale soil and incubated either at field capacity or completely saturated (Table 5). The addition of $NO_3$-N was effective in reducing the oil content. Less oil was recovered after six weeks incubation of the soil when the N was added as a K rather than Ca salt regardless of moisture conditions. Hydrogen in association with $NO_3$ was more effective than Ca or K when the soil was incubated at field capacity but not when it was saturated. The reason for the increased effectiveness of K is possibly due to its use as a nutrient. It may also result from the formation of soluble K salts of organic acids formed during oxidation of the oil. This would increase their availability to soil microorganisms. Calcium salts would be expected to be much less soluble. Probably part of the beneficial effect on plant growth of added lime is due to precipitation of organic acids as Ca salts which may otherwise restrict plant growth (see Nyborg, McGill, Carlson and Holland).

Data presented in Tables 3 and 5 demonstrate that under greenhouse conditions, less oil is decomposed when the soil is saturated than when it is at field capacity. This is to be expected and demonstrates the need for adequate drainage for most effective reclamation of oil spill sites.

Oil or its decomposition products appear to migrate down through soil. Soil samples collected at 60 and 75 cm in soil at the Redwater site in May, 1974 after oil application in July, 1973 contained significant quantities of oil. The 15 cm slice between 60 and 75 cm depth contained up to $10^4$ kg/ha of oil in May after application of approximately $2 \times 10^5$ kg/ha on the surface in July, 1973. A similar trend has been observed in greenhouse pots both with mineral (Angus Ridge) and organic (Leedale spill) soil. Results of separate examination of the oil contents of the top and bottom 7.5 cm layers of pots of organic soil indicated that even under greenhouse conditions oil migration down through soil occurs. Part of this is migration of decomposition products. Care must be exercised in interpreting these results since some of the differences are probably due to different rates of decomposition at the top and bottom of the pots. This has important ramifications to reclamation in the field. Under suitable conditions it is highly probable that substantial quantities of oil decomposition products are removed from the spill site through leaching. Reclamation techniques involving biological breakdown may, under certain circumstances, increase this process by increasing the production of intermediate metabolites.

## FIELD STUDIES

Results of field studies at Swan Hills, Leedale, Redwater and Ellerslie support the laboratory and greenhouse data (Fig. 3, Tables 6 and 7). Results similar to those in Table 6 were obtained in two additional field experiments in a wet forested soil in the Swan Hills. Rate of oil loss at the wet forest soils (Swan Hills) is more rapid than would be expected from greenhouse studies with these soils. Oil is also lost from the wet forested sites faster than from the two mineral soils studied. Probably much of the cause of this is greater leaching in the organic soils than the mineral soils. Leaching as a factor in oil removal is probably of greater significance than previously realized. Large quantities of various water-soluble materials can be recovered from these soils during oil decomposition. They appear not to be highly toxic to trout fingerlings and also appear to be readily metabolized by soil microorganisms. The total impact of these materials on soil systems has yet to be assessed.

Added nutrients accelerate oil decomposition in the field and the addition of lime and a small bacterial inoculum have also been found extremely effective in the Swan Hills. The effect of the bacterial inoculum is probably only a short term one.

Mixing in the field is also essential (Tables 6 and 7). This improves aeration and also in the case of many spill situations, places the oil in contact with a moist environment containing soil microorganisms and nutrients. In many instances in the field, oil layers seal off the soil surface and prevent $O_2$ penetration. These layers dry and even though the area may be very wet, the surface of the oil is completely dry. Oil decomposition is thus accelerated by mixing it with the unoiled material below. Breaking the oil film on top of the soil also enhances water evaporation and plant germination.

Drainage or maintenance of a proper moisture regime is essential in the field. In many situations, the site becomes progressively wetter due to the presence of oil which prevents water infiltration and evaporation. The opposite situation may also be encountered where the oil causes excessive run-off of water or allows water to pass through the soil profile without penetrating the small capillary pores which may be sealed by oil.

In this situation oil decomposition is hindered by a lack of $H_2O$ and an irrigation program may be necessary.

## FIELD APPLICATION TECHNIQUES

Drainage is essential and can be accomplished by trenching and cutting of dikes when possible. Many sites are too wet to allow this and in these cases it may be necessary to ridge the site during the winter when the surface is frozen sufficiently to hold the equipment necessary. The "piling up" experiment at the Swan Hills site was an attempt to employ this technique and was successful. The raised areas drain and contain most of the oiled soil. Decomposition can proceed rapidly and these higher windrows can then be effectively fertilized and seeded.

Fertilization should be done in a number of small increments rather than in one large dose. Too much fertilizer at one time results in poor efficiency of use due to high potential losses and salinity problems. The microbial population is probably more dynamic if nutrients are added in increments than when added as one dose. This should help accelerate the oil decomposition rate. No more than 300 kg of N/ha should be added at one time. One aspect of fertilization which must be stressed is that nutrients must be added in a balanced manner. There is no value in one nutrient alone if others are limiting. At the high rates of nutrient additions, most of the major nutrients should be added together with micronutrients. A ratio of N:P:S:K of 10:2:1:1 is probably most effective but higher rates of P may also be necessary. Further work is necessary to properly define the optimum ratio for a range of soils.

Application of fertilizer is a problem in wet areas. This cannot usually be done safely in the winter unless precautions can be taken to eliminate losses during the spring runoff of snow melt. Fertilization by helicopter is effective but expensive. Further work should be done to develop all-terrain-vehicles which could perform this type of operation. In small areas broadcasting by hand may be the only effective means of adding nutrients.

Where large fertilizer additions are necessary, lime should be included to prevent soil acidification by the fertilizer. It also helps to reduce the salinity problem. The lime should be fairly pure calcium carbonate; any material containing Dolomite ($MgCO_3$) must be avoided. Mg salts are sufficiently soluble that they will aggravate salinity problems.

Mixing or tillage operations can be performed with ordinary farm equipment or with commercially available rototillers powered by large crawler tractors. The work should be performed during the summer (when biological activity is at a maximum) if possible. If the site is too wet, rototilling in the winter is very effective. Snow should be removed to allow the site to freeze properly before any tillage operation starts. Care must always be taken to ensure that the site is not churned up by machinery being stuck. This causes problems by burying the oil at a depth where decomposition is slow. This may prevent plant growth or the oil may continue to be slowly pushed to the surface with rising water over an extended time.

Bacterial inoculants, where considered necessary, can be added effectively and economically by adding small amounts of a partially reclaimed mineral soil contaminated with a similar type of oil. This soil will contain a large population of organisms adapted to oil decomposition. Approximately one ton per acre is sufficient.

## SIDE EFFECTS OF RECLAMATION

Many side effects of oil spills and their reclamation have been observed. These result from the conditions created by the oil itself, as a result of oil breakdown and as a result of the materials added to soil to promote oil breakdown.

Soil pH is reduced by large applications of fertilizers (Table 8). Results similar to those reported in Table 12 have also been obtained with other mineral and organic soils both in the field and laboratory. The drop in soil pH can be effectively stopped by adding sufficient quantities of $CaCO_3$. One trend that also appears when comparing oiled soil with the same control soil without oil, is that the oiled soil is much better buffered against pH changes than are normal soils. For example, if all the treatments are averaged except those receiving lime and the control soil compared to the oil-contaminated soil, the pH drops down lower in the control than the oiled.

Soil pH (average of all treatments in Table 8 which received no lime)

| | Ellerslie | | Redwater | |
|---|---|---|---|---|
| | 1st crop | 2nd crop | 1st crop | 2nd crop |
| Oiled | 6.3 | 6.1 | 6.7 | 6.7 |
| Control | 5.8 | 5.8 | 6.2 | 6.1 |

However, the addition of lime to the control soil increased the pH to a greater extent than in the oiled soil.

Soil pH of limed treatments from Table 8

| | Ellerslie | | Redwater | |
|---|---|---|---|---|
| | 1st crop | 2nd crop | 1st crop | 2nd crop |
| Oiled | 7.5 | 7.1 | 7.4 | 7.0 |
| Control | 7.6 | 7.4 | 7.5 | 7.3 |

Electrical conductivity is increased by fertilizer additions (Table 8). This increase is more severe in an unoiled soil than it is in the same soil contaminated with oil and receiving the same fertilizer addition. In other soils studied both in the field and laboratory, fertilizers have had an effect on salinity similar to that reported in Table 8 . Also, the relationship between oil and soil salinity is further exemplified by the following data for soil from the Morinville spill area:

| | Average electrical conductivity in fertilized and amended soil |
|---|---|
| Oiled | 2.9 mmho/cm |
| Control | 6.7 mmho/cm |

The above data indicate the necessity of professional guidance in prescribing nutrient and amendment additions during reclamation of oil spill sites. One noteworthy observation is that even though $Ca(NO_3)_2$ appears to be beneficial for oil decomposition, it can lead to salinity problems.

Large numbers of anaerobic organisms have been found in soil contaminated with oil. Some of these reduce $SO_4^{--}$ to $S^{--}$ which can have toxic effects on plants if allowed to accumulate. This can be minimized by aerating soil properly. Others may prove to be pathogenic (Clostridia) but this possibility is still under investigation. Clostridia are much more abundant in oil-contaminated than in normal soils. There may be considerable advantage to this as some Clostridia species are capable of fixing $N_2$ and may increase the N status of these soils using energy provided by the oil.

The soluble products mentioned earlier may lead to a reduction in the $O_2$ level of water courses if they enter them and are decomposed there.

Ammonia toxicity may be a problem in some soils. Those soils which have received lime and heavy N applications are subject to this problem. If the soil pH rises above 7.5, and if substantial quantities of N are remineralized (which is likely) then the equilibrium: $NH_3 \rightleftharpoons NH_4^+$ favors $NH_3$ and will maintain this form of N. It may be toxic to plants and is also subject to large losses. The problem becomes more severe as the soil pH increases. Again, professional advice is necessary to prevent this occurrence.

One very favorable side effect is the generally increased fertility level of soils after most of the oil has decomposed. The fertility level can be expected to increase beyond the original level due to release of nutrients immobilized during oil decomposition. Noticeable increases in the population of Diptera have also been observed in reclaimed oil-contaminated soil.

## SUMMARY

Biological decomposition of oil in soil has been demonstrated in the field and laboratory.

It can probably be achieved economically in one to four years on most sites.

The requirements are:

1. Nutrients in a balanced mix applied in increments as needed and as indicated by soil analyses.
2. Maintenance of a suitable $H_2O$ and $O_2$ balance. This may involve drainage or irrigation, depending on the site.
3. Soil tillage for purposes of aeration, mixing of nutrients into soil and providing a favorable environment for microbial activity.
4. Lime may be necessary to alter the initial soil pH or to maintain a neutral pH when high fertilizer applications are necessary.
5. An inoculum of microorganisms capable of oil degradation may be useful in certain instances.

Various forms of N are available; $NO_3$-N is effective in promoting oil decomposition but may lead to some undesirable side effects.

Migration of oil decomposition products through soil occurs and may be a problem if they enter waterways in large quantity although they appear not to be highly toxic.

Side effects such as $S^{--}$ accumulation, acidity and salinity problems and development of pathogens may occur. Acidity, salinity and $S^{--}$ problems can be eliminated by proper professional management.

Beneficial side effects such as N fixation and general increase in soil fertility and biological activity following reclamation should be capitalized upon and maximized.

Professional personnel will be necessary to prescribe the proper treatment for individual sites.

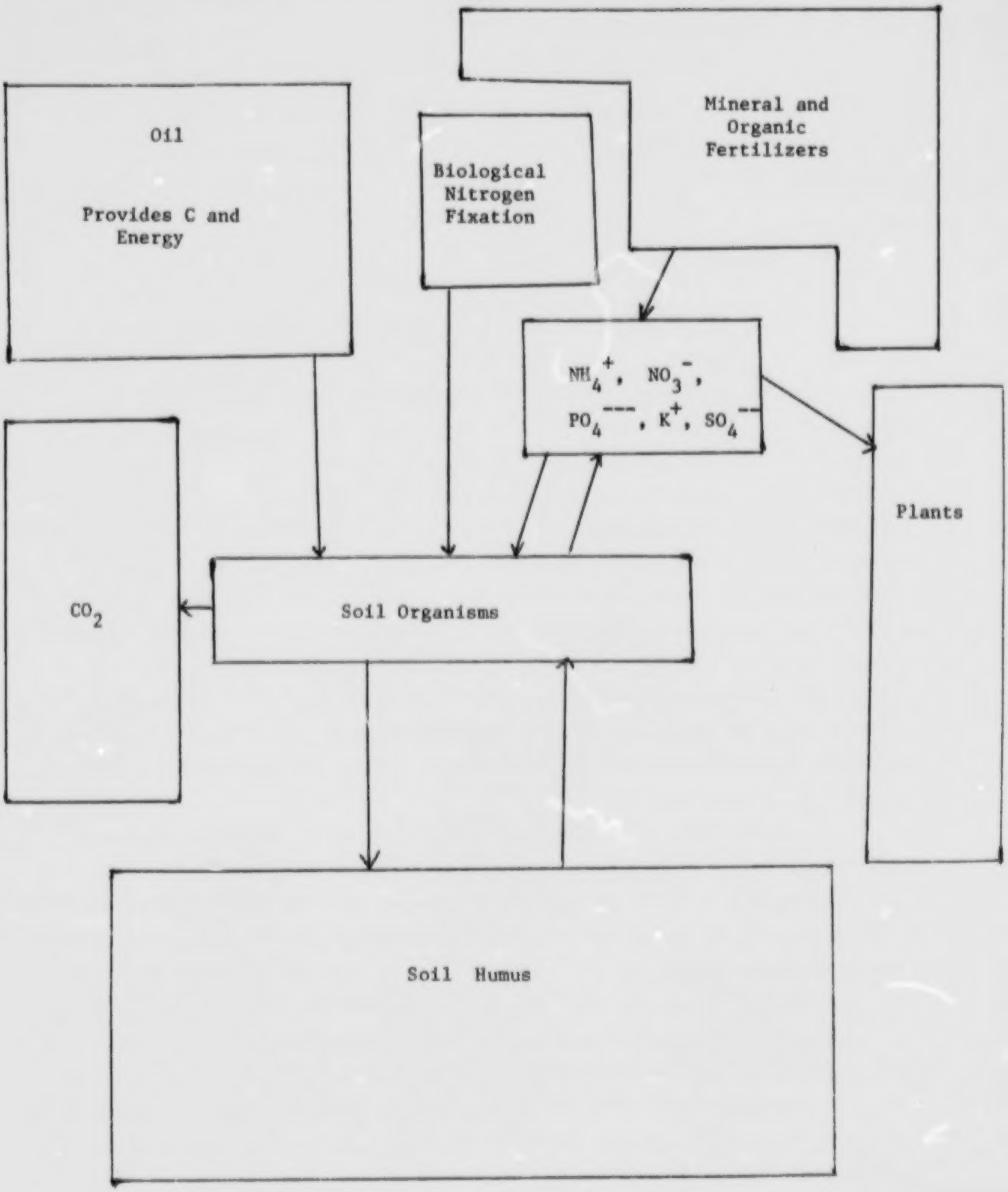
Oil
Provides C and Energy
Biological Nitrogen Fixation
Mineral and Organic Fertilizers
$NH_4^+$, $NO_3^-$, $PO_4^{---}$, $K^+$, $SO_4^{--}$
Plants
$CO_2$
Soil Organisms
Soil Humus

Fig. 1. Schematic representation of a portion of the soil system during biological decomposition of oil in soil.

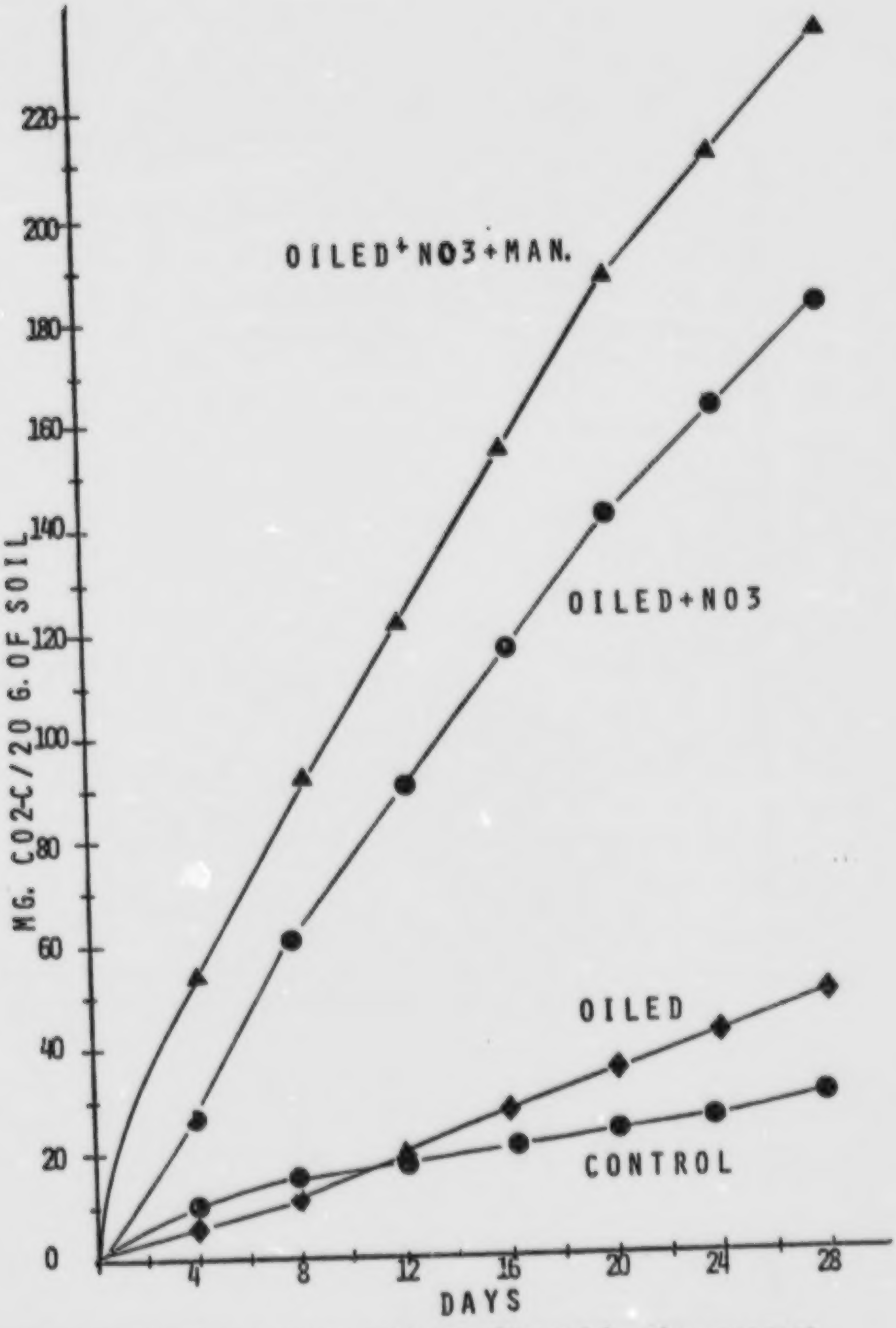

Fig. 2 $CO_2$ production by Angus Ridge soil as affected by the presence of oil and added nutrients. Original oil content =13%.

Fig. 3. Effect of Oil, Tillage and Added Nutrients on Soil Respiration Under Field Conditions.

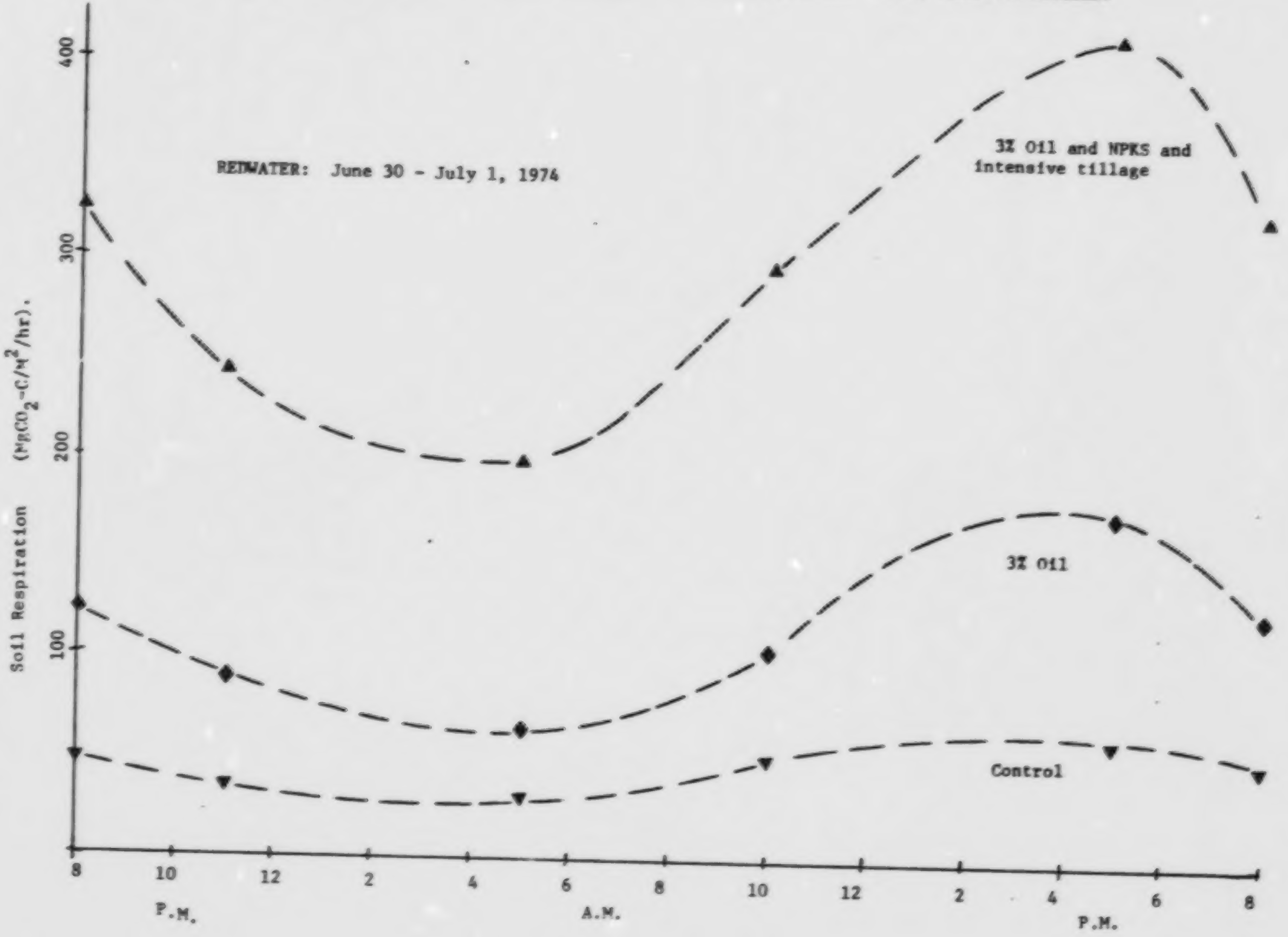

Table 1. Effect of drainage, nutrients and amendments on numbers of bacteria (plate count) and fungi (plate count) in an oil contaminated organic soil from Swan Hills, Alberta, August 9, 1973.

| | | Numbers per gram field moist soil | | | |
|---|---|---|---|---|---|
| | | Drained | | Undrained | |
| Treatment* | Soil pH | Bacteria $\times 10^6$ | Fungi $\times 10^4$ | Bacteria $\times 10^6$ | Fungi $\times 10^4$ |
| Nil | 4.5 | 71 | 100 | 2 | 40 |
| NPKS | 4.9 | 33 | 200 | 4 | 34 |
| NPKS + mixing | 4.7 | 47 | 200 | 2 | 3 |
| NPKS + mixing + amendments** | 7.2 | 200 | 17 | 44 | 3 |

* Treatments imposed, June, 1973.

** Amendments = Lime (12 tons/acre) + oiled soil inoculum (4 tons/acre - Angus Ridge soil) + micro-nutrients.

Table 2. Effect of various forms of N and amendments on the rate of oil decomposition in two Black Chernozemic soils seeded to oats in the greenhouse.

| | Oil Content as a % of Original* | | | |
|---|---|---|---|---|
| | Ellerslie | | Redwater | |
| Treatment | 1st crop | 2nd crop | 1st crop | 2nd crop |
| Nil | 97 | 70 | 91 | 62 |
| Detergent | 93 | 93 | 91 | 81 |
| $(NH_4)_2SO_4$ + PKS | 79 | 54 | 77 | 68 |
| $Ca(NO_3)_2$ + PKS | 79 | 41 | 77 | 43 |
| $NH_4NO_3$ + PKS | 80 | 56 | 83 | 60 |
| $NH_4NO_3$ + PKS + Lime | 72 | 60 | 77 | 64 |
| $NH_4NO_3$ + PKS + Detergent | 80 | 56 | 74 | 60 |

* Original oil content: Ellerslie 6.1%

Redwater 5.3%

Total incubation time was 5 months.

Table 3. Summary of results of studies on the effect of various nutrients, amendments and soil treatments on oil decomposition in an organic soil from the Leedale spill seeded to grasses and cereals.

| Treatment | Average Oil Content as % of Original Oil* |
|---|---|
| Saturated | 86 |
| Field Capacity | 75 |
| Nil | 94 |
| PKS | 92 |
| NPKS | 79 |
| NPKS + Lime | 68 |
| $NH_4$-N | 70 |
| $NO_3$-N | 78 |

* Original Oil Content = 75% oil by wt. (dry wt. basis).

Incubation time = 6 weeks.

Table 4. Effect of detergent on oil decomposition in an organic soil incubated in the greenhouse for 6 weeks at two moisture contents.

| | Oil Content as a % of Original* | | | |
|---|---|---|---|---|
| | $Ca(NO_3)_2$ + PKS | | Nil | |
| Moisture Status | 100 ppm Detergent | 1,000 ppm Detergent | 1,000 ppm Detergent | Nil |
| Field capacity | 67 | 71 | 83 | 83 |
| Saturated | 81 | 89 | 79 | 97 |

* Original oil content = 75% by wt. (dry wt. basis).

Table 5. Influence of associated cation on effectiveness of $NO_3$-N in promoting oil decomposition in an organic soil (Leedale) incubated unseeded in the greenhouse for 6 weeks.

| | % of Original Oil Content* (Ave. of 3 reps.) | | | |
|---|---|---|---|---|
| | | $NO_3$-N added with | | |
| Moisture Status | Nil | Ca | K | H |
| Saturated | 97 | 79 | 71 | 81 |
| Field capacity | 83 | 77 | 71 | 67 |

* Original oil content = 75% by wt. (dry wt. basis).

Table 6. Oil contents of a wet organic soil at Swan Hills after imposition of various treatments -- "Box and Frame" experiment.

| Sampling Dates*** | % Oil by wt. (dry wt. basis, ave. of duplicate determinations)* | | | |
|---|---|---|---|---|
| | Nil | NPKS | NPKS + Mixing | NPKS + Mixing + Amendments** |
| Drained | | | | |
| June 22, 1973 | 124 | 95 | 112 | 151 |
| July 11, 1973 | 160 | 135 | 109 | 38 |
| August 9, 1973 | 118 | 98 | 37 | 41 |
| October 20, 1973 | 107 | 107 | 16 | 21 |
| Undrained | | | | |
| June 22, 1973 | 138 | 131 | 102 | 158 |
| July 11, 1973 | 191 | 124 | 115 | 81 |
| August 9, 1973 | 103 | 53 | 86 | 53 |
| October 20, 1973 | 99 | 55 | 54 | 46 |

* Oil content was determined by Soxhlet extraction from field moist soil using $CH_2Cl_2$.

** Amendments = Lime (12 tons/acre) + oiled soil inoculum (4 tons /acre) + micro-nutrients.

*** Treatments imposed in June, 1973.

Table 7. Effect of tillage and added nutrients on oil decomposition in two Black Chernozemic soils.

| Site, Date and Depth* | Oil Content (% by wt. - ave. 3 reps.) | | | |
|---|---|---|---|---|
| | Normal Tillage | | Intensive Tillage | |
| | Nil | NPKS | Nil | NPKS |
| Ellerslie | | | | |
| 0 - 15 cm | | | | |
| August 2, 1973 | 6.7 | 6.8 | 6.7 | 6.8 |
| August 29, 1973 | 7.9 | 7.7 | 5.9 | 5.9 |
| October 30, 1973 | 6.3 | 6.0 | 5.5 | 4.3 |
| May 6, 1974 | 6.0 | 5.2 | 4.8 | 3.7 |
| 15 - 30 cm | | | | |
| August 2, 1973 | 3.2 | 3.6 | 3.2 | 3.6 |
| August 29, 1973 | 3.6 | 4.0 | 3.3 | 3.1 |
| October 30, 1973 | N.D. | N.D. | N.D. | N.D. |
| May 6, 1974 | 3.0 | 3.3 | 2.8 | 1.9 |
| Redwater | | | | |
| 0 - 15 cm | | | | |
| August 2, 1973 | 6.9 | 7.8 | 6.9 | 7.8 |
| August 29, 1973 | 5.5 | 4.2 | 5.7 | 5.0 |
| October 30, 1973 | 4.9 | 4.6 | 4.6 | 3.8 |
| May 6, 1974 | 2.3 | 2.1 | 2.7 | 1.9 |
| 15 - 30 cm | | | | |
| August 2, 1973 | 2.8 | 2.5 | 2.8 | 2.5 |
| August 29, 1973 | 2.4 | 1.7 | 2.7 | 2.6 |
| October 30, 1973 | N.D. | N.D. | N.D. | N.D. |
| May 6, 1974 | 1.2 | 1.5 | 0.9 | 1.4 |

* Treatments imposed, July 20, 1973.

Table 8. Effect of added nutrients and soil amendments on pH and conductivity of two Black Chernozemic soils seeded to oats in the greenhouse.

| | Soil pH and conductivity (ave. of 3 reps.) | | | |
|---|---|---|---|---|
| | Ellerslie | | Redwater | |
| Treatment | oiled | control | oiled | control |
| pH | | | | |
| Nil | 6.8 | 6.5 | 7.0 | 7.0 |
| Detergent (1,000 ppm) | 6.7 | 6.5 | 6.9 | 7.0 |
| $(NH_4)_2SO_4$ + PKS | 5.5 | 4.9 | 6.0 | 5.2 |
| $Ca(NO_3)_2$ + PKS | 6.8 | 6.2 | 7.1 | 6.6 |
| $NH_4NO_3$ + PKS | 6.0 | 5.5 | 6.8 | 5.8 |
| $NH_4NO_3$ + PKS + Lime | 7.5 | 7.6 | 7.4 | 7.5 |
| $NH_4NO_3$ + PKS + Detergent | 6.0 | 5.4 | 6.6 | 5.8 |
| Conductivity (mmho/cm) | | | | |
| Nil | 0.2 | 0.2 | 0.4 | 0.2 |
| Detergent (1,000 ppm) | 0.2 | 0.2 | 0.4 | 0.3 |
| $(NH_4)_2SO_4$ + PKS | 3.5 | 2.7 | 3.6 | 2.8 |
| $Ca(NO_3)_2$ + PKS | 5.2 | 5.2 | 2.4 | 5.0 |
| $NH_4NO_3$ + PKS | 3.7 | 3.5 | 4.3 | 2.7 |
| $NH_4NO_3$ + PKS + Lime | 2.0 | 4.5 | 1.6 | 4.0 |
| $NH_4NO_3$ + PKS + Detergent | 3.4 | 4.6 | 3.0 | 1.9 |

# METHODS OF ESTABLISHING PLANT GROWTH AFTER HEAVY OIL SPILLS

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## INTRODUCTION

After heavy spills of crude oil soils usually remain barren of plant growth for several years. In Alberta forests, spilled oil usually runs into low-lying areas with organic soils, and natural re-vegetation of those organic soils is especially slow. As much as 7 or 8 years after a heavy spill some organic forest soils still remain completely barren.

This paper summarizes the first-year results of a project on re-vegetation of oil spills in forests. The work is not complete, but is reported here because it shows some simple reclamation techniques are very effective in establishing plant growth on barren spills.

This paper also gives some preliminary results on re-vegetation of cultivated mineral soils which have received heavy spills of crude oil.

## RESULTS AND DISCUSSION

### The nature of forest soils after oil spills

The following observations are based on examination of a number of oil spills of various ages, most of them located in the Swan Hills - Slave Lake area. When only small amounts of oil are left on the soil after a spill, vegetation recovers quickly (generally within a year or two). The problem of lack of re-vegetation occurs where spills have been heavy, and where the area has become increasing water logged after the spill. After a heavy spill vegetation is killed by clean-up operations (bulldozing and burning), as well as by the oil). In addition, dikes are built around heavy spills to prevent spread of the oil and contamination of streams. The diked areas then become quite waterlogged because they have no drainage, because with no vegetation there is no transpiration of water, and because an oil layer at surface reduces evaporation. The soil surface is covered with a hard crust of partly-decomposed oil which becomes very hot when the sun shines on it.

Analysis of soil samples from an old but barren spill site showed both soil pH and salt content were in a range suitable for plant growth, although soil content of available nitrogen was very low. At the edge of the same spill we found three plant species establishing themselves where the soil was not too badly flooded. Those species *(Menyanthes trifoliata, Eriophorum chamissonis and carex aquatilis)* were growing in soil with oil contents ranging from about 50 to 300% by weight in the top inch with about 10% soil at 6 inches.

From these initial observations and analyses, it seemed that the reason for lack of re-vegetation of barren spills was not direct toxicity of the oil. Rather it appeared to be water-logging, and the presence of a crust at the soil surface, and possibly nutrient deficiencies. Subsequently we began field and greenhouse experiments to test those observations.

## Field experiments with an oil spill on a forest soil

Field experiments were conducted on an old barren spill 30 acres in size. An initial experiment was conducted with treatments consisting of: drainage; mixing of soil (to break up the surface crust of oil); fertilization with nitrogen, phosphorus, potassium and sulphur (NPKS); and NPKS fertilization together with addition of micronutrients, lime and soil inoculation. Drainage was simulated by placing the soil in boxes which were raised so that the surface of the soil was six inches above the water level in the spill. The treatments were imposed in late June and the soil sown to oats, timothy and reed canary grass at that time. Results for germination and yield of oats and for oil content, pH and mineral N content of soil are given in Table 1.

The germination of oats (and grasses) was very poor in non-drained treatments, and in those drained treatments where the soil was not mixed to break the oil crust (Table 1). However, oats germinated well in the drained treatments where the soil was mixed. The yield of oat forage (Table 1), and the growth of grass, was good only when the soil was drained and mixed and fertilized with NPKS or NPKS plus other amendments. Growth of oats was more than doubled by addition of amendments (lime, micronutrients, and inoculation) to the NPKS fertilizer. Subsequent experiments indicate that lime was the amendment responsible for the increased growth.

Neither drainage nor fertilization had much influence on soil pH (Table 1), which is naturally quite low in most organic forest soils. After application of lime, pH maintained itself in the near-neutral range, which is suited to good growth of a wide range of plant species. Nitrogen fertilizer was rapidly consumed by the soil in all treatments. Six weeks after start of the experiment the various treatments contained from 0 to 56 ppm of soluble mineral N (Table 1), even though 500 lb. of fertilizer-N (equivalent to about 250 ppm in the soil) had been added previous to that time. Continuing nitrogen fertilization was needed because plants periodically become N-deficient, and as shown in later experiments the reason was tie-up of nitrogen by oil decomposing microorganisms.

The two treatments which gave good plant growth (drainage and soil mixing, either with NPKS or with NPKS plus other amendments), also gave the highest rate of oil decomposition. Four months after imposition of those two treatments, content of oil in the soil was reduced to about 20%, while the non-treated soil still contained about 100% oil by weight (Table 1).

This initial experiment demonstrated that with drainage, mixing of the soil and fertilization, good plant growth could be established on a barren spill. In addition, those same treatments produced a surprisingly fast break-down of oil.

A second, well replicated field experiment was begun on the same soil in mid-August. In this experiment drainage was achieved by pumping water from an enclosed area so that the water level was lowered to 6 to 12 inches below the soil surface. Germination counts on oats and timothy three weeks after seeding showed good germination on drained treatments where the soil was mixed to break the surface crust (Table 2). In addition, plants which germinated showed no toxicity or deficiency symptoms in the treatments which were drained, mixed and fertilized.

## Greenhouse experiments with oil spills on organic forest soils

Several greenhouse experiments were untaken, but are reported only briefly, because essentially they confirmed the field results. In one experiment the soil used was taken from a barren, waterlogged site near Leedale, Alberta, where a spill had occurred 2 years previously. Most of oil remaining in soil was concentrated near the soil surface, but some oil occurred at depths of as much as 1 or 2 feet. The soil sample used for the greenhouse experiment contained 75% oil by weight.

The soil was placed in pots, sown to oats, timothy and alfalfa,

Table 1. Effect of drainage, mixing and fertilization on germination and growth of oats, and pH, mineral N content, and oil content of a barren forest soil which had previously received an oil spill.

| | Growth of oats | | Soil analysis | | |
|---|---|---|---|---|---|
| Treatment | Germination (%) | Yield ($g/32\ ft^2$) | pH[1] | $NH_4 + NO_3$ nitrogen (ppm)[2] | Oil (%)[1] |
| Not drained | | | | | |
| - Nil | 0 | 0 | 4.8 | 0 | 99 |
| - NPKS[3] | 0 | 0 | 4.9 | 1 | 55 |
| - NPKS; soil mixing | 0 | 0 | 5.3 | 0 | 54 |
| - NPKS; soil mixing; and amendments[4] | 0 | 0 | 6.6 | 0 | 46 |
| Drained | | | | | |
| - Nil | 2 | 1 | 4.5 | 1 | 107 |
| - NPKS | 2 | 2 | 4.8 | 25 | 107 |
| - NPKS; soil mixing | 80 | 95 | 4.9 | 56 | 16 |
| - NPKS; soil mixing; and amendemnts | 80 | 210 | 7.0 | 1 | 21 |

[1] Sample for pH and oil determination taken 4months after imposition of treatments.

[2] Samples for $NH_4$ and $NO_3$ determination taken 6 weeks after imposition of treatments.

[3] N, P, K and S added at a rate of 800, 200, 200 and 80 lb/acre, respectively.

[4] Amendments consisted of: $CaCO_3$ at 12/acre; inoculation with 4 tons/acre of a Black cultivated soil which previously had been contaminated with oil and contained a large population of oil decomposing organisms; plus an addition of micronutrients (Fe, Mn, Zn, Cu, B, Mo).

and soil moisture content kept at field capacity. Treatments consisted of various fertilizer applications and lime.

Germination of oats was good on all treatments, but growth was greatest when NPKS fertilizer and lime were applied (Table 3). Germination of alfalfa and timothy is not shown in Table 3, but was good on all treatments. Growth of both alfalfa and timothy was greatest when the soil received NPKS fertilizer and lime (Table 3).

Table 2. Effect of various treatments on germination of oats and timothy sown on a barren forest soil which had previously received an oil spill.

| Treatment | Germination (%) | |
|---|---|---|
| | Oats | Timothy |
| **Not drained** | | |
| - Nil | 4 | 3 |
| - NPKS[1] | 2 | 0 |
| - NPKS + amendments[2] | 0 | 0 |
| - Soil mixed | 5 | 0 |
| - Soil mixed; NPKS | 10 | 3 |
| - Soil mixed; NPKS + amendments | 7 | 0 |
| **Drained** | | |
| - Nil | 52 | 25 |
| - NPKS | 60 | 18 |
| - NPKS + amendments | 77 | 28 |
| - Soil mixed | 83 | 47 |
| - Soil mixed; NPKS | 75 | 43 |
| - Soil mixed; NPKS + amendments | 75 | 43 |

[1] N, P, K and S applied at rates of 300, 100, 100, 40 lb/acre, respectively.

[2] Amendments consisted of lime (12 tons $CaCO_3$/acre), micronutrients, and a soil inoculum (4 tons/acre).

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The ammonium ($NH_4$) and nitrate ($NO_3$) forms of nitrogen fertilizer were compared in the experiment. Without liming the $NH_4$ fertilizer depressed pH from an original value of 6.4 to 5.2, and as a consequence growth of alfalfa (which is very acidity-sensitive) was depressed (Table 3). The $NO_3$ fertilizer however increased pH and produced good growth of alfalfa. These results show that heavy applications of ammonium-based nitrogen fertilizer should not be used on oil spills unless lime is added to prevent depression of soil pH.

The greenhouse experiment demonstrated various differences among species in response to form of applied nitrogen and to application of lime, but that rather involved topic will not be dealt with here. The main finding of the experiment was simply that three plant species germinated and grew when fertilizer and lime were applied to a previous barren soil high in oil content, provided that the moisture content of the soil was not excessive.

Another greenhouse experiment was conducted with various species of trees on organic soils from two spill sites, and on two similar soils which had not received a spill. On the two spill soils (containing 60 and 103% oil by weight) there was moderate to very severe damage in seedlings of Black Spruce, White Spruce, Larch, Dogwood, and Willow. However, many of the seedlings did survive for a 2-month period and make good growth during that time (Table 4).

The greenhouse experiment with tree seedlings indicated that it may be possible to establish some tree species on barren spills high in oil content. However, we have not yet defined which are the best soil treatments, or the most suited tree species.

### Greenhouse experiments with cultivated farm soils which have received oil spills

Three cultivated farm soils which had received spills of crude oil were used in greenhouse experiments to test oil decomposition and plant growth after various treatments.

The one soil was from a spill near Morinville, and the sample, which contained 13% oil by weight, was taken one month after occurrence of the spill.

Table 3. The germination & yield of oats, timothy and alfalfa, and soil pH, in a greenhouse experiment with a barren organic soil contai 75% oil.

| Treatment* | Soil pH | Germination of oats (%) | Yield of 6-week old plants (g/pot) | | |
|---|---|---|---|---|---|
| | | | Oats | Alfalfa | Timothy |
| None | 6.4 | 75 | 2.1 | 0.10 | 0.07 |
| PKS fertilizer | 6.3 | 70 | 3.3 | 0.14 | 0.05 |
| $NH_4$ PKS fertilizer | 5.2 | 80 | 3.9 | 0.10 | 0.09 |
| $NO_3$ PKS fertilizer | 7.2 | 90 | 3.6 | 0.30 | 0.12 |
| $NH_4$ PKS fertilizer; plus lime | 6.8 | 90 | 5.3 | 0.25 | 0.22 |
| $NO_3$ PKS fertilizer; plus lime | 7.5 | 90 | 4.6 | 0.29 | 0.12 |

* N, P, K and S fertilizers were applied at rates of 500, 200, 200 and 100 lb. per acre respectively. The $NH_4$-form of N was $NH_4Cl$ plus $NH_4(SO_4)_2$, and the $NO_3$-form was $Ca(NO_3)_2$. Lime ($CaCO_3$) was applied at a rate of 6 tons per acre.

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The spill soil and control soil (taken adjacent to the spill) were first cropped for an 8-week period in the greenhouse. Subsequently, the two soils received various treatments and were then cropped to oats for a 3-month period, and then sampled for chemical analysis. The results (Table 5) show very low yield of oat plants on the oiled soil when not fertilized, but yields were increased more than 5-fold by a heavy fertilizer application. Yields on the fertilized oiled soil were greater than on the unfertilized control soil, and two-thirds as high as those on the fertilized control soil (Table 5). That is, with fertilizer application plants on the oiled soil yielded nearly as much as those on the control soil. Yields were not increased by application of a detergent or by application of manure.

Table 4. New growth of 3-year old black spruce seedlings 8 weeks after being planted in organic soil from an oil spill, and in a control soil.

| Soil[1] | Treatment[2] | Seedlings with new top growth (%) | Seedlings with new root growth (%) |
|---|---|---|---|
| Control | None | 100 | 100 |
| | NPKS and lime | 100 | 100 |
| Oiled | None | 100 | 100 |
| | NPKS and lime | 67 | 83 |

[1] The oiled soil contained 60% oil by weight and control soil contained none.

[2] N, P, K and S fertilizers were applied at rates of 700, 200 270 and 36 lb/acre respectively; and lime ($CaCO_3$) was applied at 5 tons/acre.

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Of the three nitrogen fertilizers, $Ca(NO_3)_2$ did not significantly decrease pH of the oiled soil, but $(NH_4)_2SO_4$ lowered pH by about 1.5 units (Table 5). On many soils that amount of acidification would harm growth of acidity-sensitive crops (e.g. alfalfa and barley).

The soluble salt content of soil was increased most by $Ca(NO_3)_2$ and $(NH_4)_2SO_4$ (Table 5). However, fertilizers produced a much greater salt accumulation in the control soil than in the oiled soil.

This greenhouse experiment indicated that on cultivated mineral soils plant growth can be established soon after oil spills, and the heavy fertilization needed for good plant growth has little harmful effect on the soil and speeds oil breakdown. Specifically, the oiled soil initially had 13% oil by weight (a very high content to be held in a mineral soil), but in the case of one of the better fertilizer treatments ($NH_4NO_3$ + PKS) oil content had after 5 months dropped to less than half of the original, yield was nearly as good as on the similar soil not affected by the oil spill, soil pH was still near neutral, and soil content of salts was not excessive.

Table 5. Yield of oats, and pH and electrical conductivity of soil at time of harvest, for a soil from an oil spill on farm land, and for similar control (non-oiled) soil.

| | | | Soil analyses | |
|---|---|---|---|---|
| Soil | Treatment | Yield of oat plants (g/pot) | pH | Conductivity** (mmhos/cm) |
| Oiled | None | 0.9 | 7.1 | 1.6 |
| | Detergent | 0.9 | 6.7 | 0.8 |
| | $Ca(NO_3)_2$ + PKS | 6.4 | 6.9 | 4.2 |
| | $NH_4NO_3$ + PKS | 6.0 | 6.5 | 2.1 |
| | $NH_4(SO_4)_2$ + PKS | 5.9 | 5.7 | 4.1 |
| | $NH_4NO_3$ + PKS; and Lime | 5.2 | 7.3 | 2.0 |
| | $NH_4NO_3$ + PKS; and Manure | 5.8 | 6.8 | 2.7 |
| | $NH_4NO_3$ + PKS; and Detergent | 5.6 | 6.6 | 2.0 |
| Control | None | 3.4 | 7.8 | 1.0 |
| | $NH_4NO_3$ + PKS | 9.4 | 6.6 | 5.4 |
| | $NH_4NO_3$ + PKS; and Manure | 8.9 | 6.8 | 8.0 |

* N, P, K and S as fertilizer applied at rates of 700, 140, 525, 70 lb/acre, respectively. Lime ($CaCO_3$) and manure applied at rates of 10 and 4 tons per acre, respectively. Detergent (Polycomplex A-11) added at a rate of 1 ton per acre.

** Electrical conductivity of a water extract of the soil.

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A greenhouse experiment was also conducted with two other pairs of oiled and control soils. The soils were taken in October from a 0- to 6-inch depth at experimental sites near Ellerslie and Redwater, where artificial spills of paraffinic crude oil had been made four months earlier. Both sites were on cultivated Black Chernozemic soils. The oiled soils for the greenhouse experiment were taken where oil had been spilled at a rate of 26,000 gallons per acre.

The top soil from Ellerslie (a silty clay loam) contained 6.1% oil by weight, and the soil from Redwater (a loam) contained 5.3%. There was good internal drainage in the soils at both sites, and some oil had percolated into the subsoil. Consequently, the oil content of the two topsoils probably represented typical amounts of oil retained in well-drained mineral soils after heavy spills.

In the greenhouse experiment the soils were placed in pots, various fertilizer and amendment treatments were applied, and the soils cropped twice to oats (each cropping lasting for two months). The oiled soils did not wet readily on addition of water, but good crop germination was obtained using frequent waterings. Yields of oat plants were much lower on the oiled soils than on the control soils (Table 6). For the first cropping, the best-yielding treatments on the oiled soils produced only 10% as much growth as fertilized control soil. However, for the second cropping yields on some treatments of the oil soils had increased to 30% of those on the fertilized control soils. The plants on most treatments of the oiled soils showed no toxicity symptoms, and lower yields on the oiled soils may have been caused primarily by poor wettability of those soils.

There were considerable differences in yields among treatments employing different nitrogen fertilizers on the oiled soils. Generally, the highest yields (and healthiest plants) were produced by $NH_4NO_3$, and the lowest by $(NH_4)_2SO_4$ or $Ca(NO_3)_2$. At the same time, the most rapid decomposition of oil occurred with $Ca(NO_3)_2$ fertilizer (see McGill, *et al*. in these Proceedings). Our results are not sufficiently complete to be sure of the explanation for the lower yields with some nitrogen fertilizers, but probably they were the result of too low a soil pH with the $(NH_4)_2SO_4$ and too high a soil pH with the $Ca(NO_3)_2$.

Table 6. Yield of first and second crops of oats grown in the greenhouse on oiled and control soils taken from two spills on cultivated mineral soils.

| Site | Soil | Treatment* | Yield of plants (g/pot) | |
|---|---|---|---|---|
| | | | First crop | Second crop |
| Ellerslie | Oiled | None | 0.3 | 0.5 |
| | | $(NH_4)_2SO_4$ | 0.5 | 1.0 |
| | | $NH_4NO_3$ | 1.0 | 2.2 |
| | | $Ca(NO_3)_2$ | 1.0 | 1.3 |
| | | $NH_4NO_3$; and lime | 1.0 | 2.0 |
| | | $NH_4NO_3$; and detergent | 0.5 | 2.7 |
| | Control | None | 1.8 | 0.6 |
| | | $NH_4NO_3$ | 9.7 | 8.3 |
| Redwater | Oiled | None | 0.3 | 0.4 |
| | | $(NH_4)_2SO_4$ | 0.5 | 1.4 |
| | | $NH_4NO_3$ | 0.3 | 2.2 |
| | | $Ca(NO_3)_2$ | 0.4 | 0.6 |
| | | $NH_4NO_3$; and lime | 0.9 | 0.7 |
| | | $NH_4NO_3$; and detergent | 0.4 | 1.8 |
| | Control | None | 1.0 | 0.8 |
| | | $NH_4NO_3$ | 8.0 | 7.4 |

* All treatments receiving nitrogen fertilizer also received applications of P, K and S. Rates of N, P, K and S were 900, 170, 215 and 85 lb/acre, respectively for the first crop; and 700, 200, 250 and 50 lb/acre, respectively for the second crop. Lime ($CaCO_3$) was applied at 10 tons per acre, and detergent (Polycomplex A-11) at 1000 ppm.

## CONCLUSIONS

Our preliminary results indicate the major reason for lack of revegetation after heavy spills of crude oil is not direct toxicity of the oil to plants. Instead, the reason is waterlogging or poor physical condition of the soil, combined with severe deficiency of nutrients (especially nitrogen) which starves plants and delays oil decompositions.

Good growth of timothy and oats was obtained on a barren spill site on an organic soil simply by drainage, working the soil to break the surface oil crust, and heavy fertilization. Greenhouse experiments suggested those techniques may be applicable to reclamation of most spills on organic forest soils.

Growth of oats was obtained in greenhouse experiments on three cultivated mineral soils which received heavy spills of crude oil. However, on two of those soils yields were severely depressed by the oil, even though the soils were well fertilized. The low yields on those oiled soils was probably the results of poor soil wettability.

Our observations suggest that oil spills on organic forest soils are probably more easily reclamated than those on cultivated mineral soils.

## ACKNOWLEDGEMENT

Most of the results given in this paper are taken from a project supported by Canada Department of Environment through Contract No. OSP3-0073 with the Northern Forest Research Centre, Edmonton. Other results are from a project supported by the Alberta Environmental Research Trust.

# *RECLAMATION OF OIL SANDS TAILINGS*

# SULFOMETHYLATED HUMIC ACID PRODUCTS AS SOIL CONDITIONERS AND FERTILIZERS FOR THE RESTORATION OF THE ATHABASCA OIL SAND MINING AREA*

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## INTRODUCTION

Protection of the environment at the Athabasca oil sand mining region is of great concern to the regulatory authorities and scientists of our province. One of the numerous unique technological problems is restoration and revegetation of the mining area after extraction of bitumen from the oil sand formation.

Sandy soils are not cohesive and do not agglomerate by themselves to form stable aggregates. They are loose and therefore do not provide a stable soil structure for plants to grow in, are easily drifted by strong winds and are susceptible to water erosion. Their hydraulic conductivity is very high; consequently, water infiltrates rapidly, carrying with it vital plant nutrients. Surface temperatures may become excessive and cause rapid desiccation of surface layers. The soils usually do not contain an adequate bacterial or fungal population to promote decomposition of dead vegetation.

The sandy soils which will be formed after the extraction of the bitumen from the Athabasca oil sand formation may also have high alkalinity and high salt content due to the use of caustic in the separation process. Since recovery of bitumen by the hot-water process is 90 to 93%, about 7 to 10% of the bitumen will remain in the tailings. This material or its degradation products could be potentially phytotoxic.

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* Contribution number 672 from the Research Council of Alberta, Edmonton, Alberta, Canada.

Sulfomethylated humic acids increase soil aggregation and reduce infiltration rates in sandy soils (1). Their N-content also acts as a nitrogen fertilizer. Sulfomethylated humic acids are slightly acidic (pH ~6.5) and contain a substantial number of acidic functional groups which can easily exchange their ammonium cation with the alkali cation present in the sands. A program of detailed greenhouse studies was undertaken to determine performance of sulfomethylated humic acid products as soil conditioners and fertilizers for the sandy soils of the Athabasca mining area. This is an extension of the greenhouse and field trials which the Product Research and Development Division of Alberta Research Council began in 1972 on the sandy soils in the Youngstown region of Alberta.

## MATERIALS AND METHODS

Elemental analyses of soil and plant samples were carried out by the Alberta Department of Agriculture, Soil and Feed Testing Laboratories, and the Alberta Research Council analytical laboratories, employing common analytical techniques (2). The moisture content of sand at 1/3 bar (250 mm pressure) was determined with a pressure plate extractor, catalogue No. 1200, Soil Moisture Equipment Company.

The sources of sulfomethylated humates, their preparation and analyses have been published earlier in these proceedings (1). For all studies, the sand was air dried and sieved to 2 mm grain size.

### Growth Chamber Experiments

Two studies were undertaken, each using 300 grams of sand. Solutions of sulfomethylated humates, ammonium nitrate and ammonium sulfate, were applied at rates of 100 ppm and 200 ppm available nitrogen per application. Three replicates of each treatment were conducted.

Study I: Reed Canary grass was sown (150 mg of seed, approximately 150 seeds per pot).

Study II: Bromegrass was sown (300 mg of seed, approximately 100 seeds per pot)

In each experiment, pots were grouped in a randomized block, covered with "Earthaid" to control water evaporation and watered to field capacity (3.5%). The pots were placed into a germinator for 6 days before being placed into the growth chamber, where growing conditions were set to match as closely as possible the average climatic conditions of the Athabasca region of Alberta:

| | | |
|---|---|---|
| Day: | Daylight | 14 hours (500 foot candles) |
| | Temperature | 20.1 °C ± 2 |
| | Humidity | 53.9% ± 4 |
| Night: | Duration | 10 hours |
| | Temperature | 7.2 °C ± 2 |
| | Humidity | 81% ± 4 |

The water level was not allowed to fall below 25% of the field capacity by soil weight during the plant growth period of 30 days, after which time the plants were harvested. The same conditions were maintained to reestablish new growth.

After a 30-day growing period the plants had shown very little progress and were yellowish-purple in color due to deficiencies of phosphorus, potassium and micronutrients. It was therefore decided that harvest should not be carried out and that the pots should receive additional nutrients. A nutrient solution of Shive and Robbins 1 (3) was applied at a rate of 100 ml per pot (20 ml/pot/5-day period) during a second growing period of 30 days, after which they were harvested. The harvested crops were dried at 50 °C, weighed, ground and analyzed. After the second harvest, the soil was allowed to air dry, sieved through a 2-mm sieve, and analyzed.

## Soil Structure Experiments

Aggregate Analysis: The sulfomethylated humic acids at rates of 0.27%, 0.54%, and 2.7% by weight were mixed with 500 grams of soil and placed in an aluminum dish 15 cm in diameter and 4 cm deep. Eight replicates of each treatment were kept at 10 °C to 20 °C and watered to field capacity (3.5%) every week for five weeks. Aggregates could not be determined by wet sieving because sand granules were covered by an oil film which made them water-repellent, therefore, the dry-sieving procedure was followed (4).

Hydraulic Conductivity Experiments: To determine the hydraulic conductivity, 300 grams of sand was placed into 4 x 45-cm glass tubes filled by pouring the sand into each from a standard height and saturated by soaking the bases of the tubes in distilled water. Aqueous solutions (200-ml head) of each treatment (sulfomethylated humate) of 100 ppm, 200 ppm, 300 ppm and 600 ppm nitrogen content were applied on the surfaces of the sand in triplicate columns. The hydraulic conductivity was determined by the "Falling Head" method (4).

## RESULTS AND DISCUSSION

There was a significant initial increase in growth of Reed Canary grass with all forms of applied nitrogen (Table I), and of bromegrass with some forms of applied nitrogen, but no clear trend was established (Table II). Growth did not continue appreciably after the first 30 days. Application of a complete nutrient solution produced significant growth in all treatments, including the control (Tables I and II). This test demonstrated that the growth of these two species is not significantly affected by either residual bitumen or the alkaline nature of the tailings.

Use of sulfomethylated humates significantly increases the mean weight diameters of aggregates at additive application levels of 0.27% (100 ppm N), 0.54% (200 ppm N), and 2.70% (1000 ppm N). This effect is probably from the cementation of particles by the humic additives (Table III).

Sulfomethylated humates also significantly decreased the rates of hydraulic conductivity through the tailings. These additives are well known as clay dispersants. Dispersed clays decrease the permeability of the sand bed.

## ACKNOWLEDGEMENTS

We wish to thank Dr. R. R. Cairns, Canada Department of Agriculture, Solonetzic Research Station, Vegreville, Alberta, for many helpful discussions, and Mr. E. Anderson and Miss V. Harrison for their technical assitance.

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## TABLE I

### Effect of Various Materials on Yields of Reed Canary Grass

| Treatment | Nitrogen Applied (ppm) | First Harvest (g/pot) | Second Harvest* (g/pot) | First and Second Harvest (g/pot) |
|---|---|---|---|---|
| Control | 0 | .120 | .960 | 1.08 |
| Ammonium Nitrate | 100 | .170 | .934 | 1.10 |
| Sulfomethylated Humate | 100 | .195 | 1.010 | 1.21** |
| Ammonium Sulfate | 100 | .171 | .960 | 1.13 |
| Ammonium Nitrate | 200 | .285 | 1.015 | 1.30** |
| Sulfomethylated Humate | 200 | .228 | 1.028 | 1.25** |
| Ammonium Sulfate | 200 | .212 | .948 | 1.16** |
| Sulfomethylated Humate (p-2) | 100 | .178 | .960 | 1.14 |
| Sulfomethylated Humate (p-2) | 200 | .182 | .902 | 1.08 |
| L.S.D. at 95% level of probability | | .04 | .27 | .07 |

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* Shive and Robbins (1942) I Nutrient Solution added.

** Significantly better than controls.

## TABLE II

### Effect of Various Materials on Yields of Bromegrass

| Treatment | Nitrogen Applied (ppm) | First Harvest (g/pot) | Second Harvest* (g/pot) | First and Second Harvest (g/pot) |
|---|---|---|---|---|
| Control | 0 | .182 | .675 | .86 |
| Ammonium Nitrate | 100 | .321 | .683 | 1.00** |
| Sulfomethylated Humate | 100 | .233 | .744 | .98 |
| Ammonium Sulfate | 100 | .292 | .589 | .88 |
| Ammonium Nitrate | 200 | .388 | .579 | .97 |
| Sulfomethylated Humate | 200 | .273 | .701 | .97 |
| Ammonium Sulfate | 200 | .221 | .615 | .84 |
| Sulfomethylated Humate (p-2) | 100 | .242 | .669 | .91 |
| Sulfomethylated Humate (p-2) | 200 | .229 | .734 | .96 |
| L.S.D. at 95% level of probability | | .091 | .076 | .11 |

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* Shive and Robbins (1942) I Nutrient Solution added.

** Significantly better than controls.

## TABLE III

Effect of Sulfomethylated Humates on Mean Weight Diameter (M.W.D.) of Aggregates of G.C.O.S. Sands

| Treatment | Application (%) | G.C.O.S. Sand M.W.D. (mm) |
|---|---|---|
| Control | 0 | .292 |
| Sulfomethylated Humate | 0.27 | .325 |
| Sulfomethylated Humate | 0.54 | .343 |
| Sulfomethylated Humate | 2.70 | .397 |
| L.S.C. at 95% level of probability | | .06 |

## TABLE IV

Effect of Sulfomethylated Humates on the Hydraulic Conductivity of G.C.O.S. Sands

| Material | Nitrogen In Solution (ppm) | --------Depth of Water Infiltration (cm/min)-------- | | | |
|---|---|---|---|---|---|
| | | I | II | III | Average |
| Control | Distilled Water | .200 | .198 | .300 | .236 |
| Sulfomethylated Humate | 100 | .263 | .247 | .300 | .270 |
| Sulfomethylated Humate | 200 | .324 | .300 | .132 | .252 |
| Sulfomethylated Humate | 300 | .071 | .038 | .052 | .053 |
| Sulfomethylated Humate | 600 | .014 | .006 | .007 | .009 |
| L.S.D. at 95% level of probability | | | | | .116 |

## TABLE V

### Some Characteristics of Sand Samples From the Hot-Water Process

| Source | Toluene Extractibles | Percentage of Solids | pH | $OH_2$ |
|---|---|---|---|---|
| G.C.O.S. | 0.6% | 92 | 8.8 | 7.4 |
| Syncrude | 0.2% | 97 | 7.8 | 2.8 |

## TABLE VI

### Shive and Robbins (1942) I Nutrient Solution

| | g./l. | Molar |
|---|---|---|
| $Ca(NO_3)_2$ | 0.938 | 0.0045 |
| $(NH_4)_2SO_4$ | 0.0924 | 0.0007 |
| $KH_2PO_4$ | 0.313 | 0.0023 |
| $MgSO_4 7H_2O$ | 0.567 | 0.0023 |
| $FeSO_4 7H_2O$ | 5.5 mg | |
| $H_3BO_3$ | 0.57 mg | |
| $MnSO_4 \cdot H_2O$ | 0.57 mg | |
| $ZnSO_4 \cdot 7H_2O$ | 0.57 mg | |

# RECLAMATION OF MINED LAND, GREAT CANADIAN OIL SANDS LTD. LEASE SITE, TAR ISLAND, ALBERTA

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## INTRODUCTION

In the open pit method of mining oil sands at G.C.O.S. lease site, two operations are performed that disturb the earth and have an impact upon the environment. Ground cover is cleared away and overburden material on top of orebody removed to waste dumps in areas beyond the mining limits. Oil extraction operations produce mountains of fine uniform tailings sand at the tailings dyke site. Overburden waste dumps and sand tailings dyke are exposed to erosion by wind and water. The tailings dyke erodes more than the waste dumps.

## INITIAL WORK ON RECLAMATION OF TAILINGS DYKE

The original concept for constructing the dyke to contain tailings slurry was to build walls of clay from overburden stripping. The first forty foot vertical interval was constructed in this manner. Due to mounting costs with increased hauling distances, new techniques were developed to keep costs within bounds. The dyke is now hydraulically built with tailings sand.

Within a year of placing tailings sand on dyke walls, it was discovered that 15 - 20 m.p.h. winds create major sand storms and heavy rainstorms erode deep gullies in the banks. Proposals to stabilize the sands with a 3-4 foot blanket of lean oil sands or gravel were shelved in favor of establishing a vegetative cover. With this objective in mind, Mr. O. G. Bratvold, Director of Plant Industry Division, Alberta Department of Agriculture, was contacted and the problem discussed. This resulted in Mr. A. W. Goettel, Head of Soil Branch, and Mr. D. H. Laverty, Director of Soil and Feed Testing Laboratory, Dept. of Agriculture, visiting the plant site in the fall of 1969 and making a tour of the tailings dyke, waste dump, and muskeg areas. Laboratory and growth room tests of tailings sands, overburden clay and muskeg were suggested before attempting field trials.

Initial analysis of the tailings sand indicated that it was practically barren of the three major plant nutrients, nitrogen, phosphorus and potassium. Soil reaction was highly alkaline due to treating the oil sands with caustic soda in the extraction process. Analysis of the overburden clay and muskeg showed they were higher in available nutrients and, mixed with sand, would provide a suitable seedbed by reducing alkalinity and improving water percolation and moisture retention.

## GROWTH ROOM STUDY

Bulk samples of tailings sand, overburden clay and peat from the lease site were shipped to the Soil and Feed Testing Laboratory, Edmonton, mixed in several combinations, potted and fertilized at various levels and sown separately to several species of grass (bromegrass, pubescent wheatgrass, streambank wheatgrass, crested wheatgrass, creeping red fescue) and legumes (alsike clover and sweet clover).

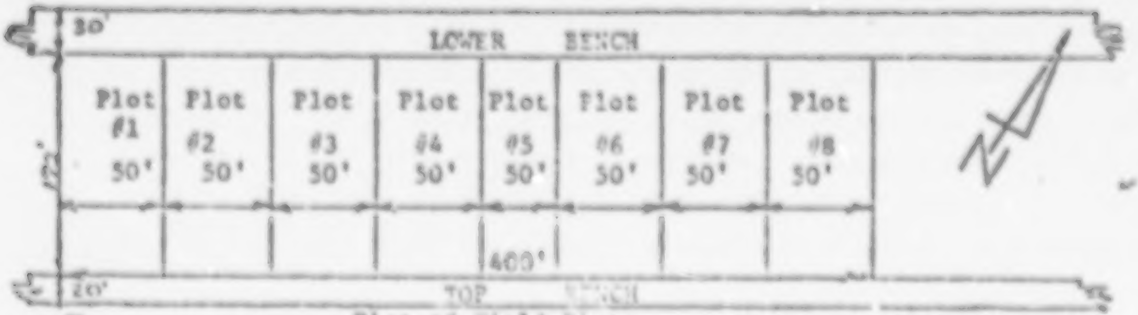
Excellent plant growth was obtained in pots containing a mixture of clay and sand, muskeg and sand, and a mixture of clay, muskeg, and sand. Growth on pure sand was maintained only by frequent application of water and fertilizer.

The growth room studies resulted in the following recommendations:

1. "Good clay" (with no oil sands) and muskeg should be tilled into the sand for a seedbed.
2. A high rate of a complete fertilizer should be incorporated into the seedbed before planting.
3. A mixture of forage grasses and legumes should be seeded at higher than normal rate to ensure adequate germination.
4. An irrigation network should be set up to supply water for germination and seedling establishment.

## FIELD TEST PLOTS

To verify and assess recommendations resulting from studies conducted in growth rooms, eight field plots as shown in sketch below were laid out on sand slope at north end of tailings dyke in spring of 1970.


30'
LOWER BENCH
Plot #1 50'
Plot #2 50'
Plot #3 50'
Plot #4 50'
Plot #5 50'
Plot #6 50'
Plot #7 50'
Plot #8 50'
400'
20'
TOP BENCH
N

Plan of Field Plots

PLAN OF TEST PLOTS (Vertical Interval between benches = 43')

Overburden clay and muskeg were trucked and dumped on the top bench. Tailings sand was added as specified and the mass mixed by rototilling, this was spread on slope with a tracked dozer.

| PLOT # | SEEDBED MIXTURE | RATIO OF MIXTURE | RATIO OF FERTILIZER |
|---|---|---|---|
| #1 | Sand only | | 800 lb./acre, 8 - 24 - 24 |
| #2 | Sand & Muskeg | 3" - 4" muskeg spread over top of sand | 800 lb./acre, 8 - 24 - 24 |
| #3 | Sand & Muskeg | 4" sand 4" muskeg mixed w/rotovator | 800 lb./acre, 8 - 24 - 24 |
| #4 | Sand & Clay | 4" sand 4" clay mixed w/rotovator | 600 lb./acre, 8 - 24 - 24 |
| #5 | Sand, Muskeg & black clay | 4" sand 8" muskeg 4" black clay | 800 lb./acre, 8 - 24 - 24 |
| #6 | Sand, Muskeg & black clay | 4" sand 8" muskeg 4" black clay | 600 lb./acre, 8 - 24 - 24 |
| #7 | Sand, Muskeg & clay fill | 4" sand 4" muskeg 4" clay fill | 800 lb./acre, 8 - 24 - 24 |
| #8 | Sand, Muskeg & clay fill | 4" sand 4" muskeg 4" clay fill | 1000 lb./acre, 8 - 24 - 24 |

## FIELD TEST PLOTS

Following seedbed preparation, the plots were fertilized using a manually operated cyclone broadcaster and harrowed. A seed mixture consisting of brome grass 33%, crested wheatgrass 24%, creeping red fescue 15%, white clover 14%, alsike clover 14% by weight was broadcast at a rate of 30 pounds per acre and harrowed in. The last pass of the harrows was made across slope to reduce erosion.

Fortunately, there was ample rainfall following seeding to germinate seeds and support plant growth until an irrigation system (designed by Water Resources Division, Department of Environment) was installed in July. On the basis of soil tests and plant analysis, additional fertilizer (100 lbs./acre 8-24-24 plus 100 lb. per acre 34-0-0) was applied to all plots at the beginning of August to improve plant growth and ensure winter survival.

Plots with a mixture of clay, muskeg, and sand retained more plant nutrients at the crest of the slope than plots without clay. Plant nutrients at the crest of Plot 3 were not as plentiful as in plots with clay mixture but the plot appeared equal in plant performance. This deficiency in seedbed of muskeg and sand could be overcome by reducing the quantity of fertilizer per application and increasing the number of applications.

The extra expense of hauling suitable clay to mix with the sand did not warrant the advantage gained in retaining more plant nutrients at the crest of slope, therefore, a mixture of muskeg and sand on a 1:1 ratio was recommended for seedbeds of future areas to be revegetated on tailings dykes.

Without irrigation, seed germination and plant growth on sand only is too slow to keep ahead of wind-eroded sand. There was 95% failure of legumes and no reduction of soil PH (7.5 - 9.5).

By irrigating Plot #1 for two consecutive growing seasons, the stand of grass obtained minimized wind erosion. Since then,precipitation has been the sole source of moisture. The predominant species is creeping fescue, which has filled all barren areas to form a dense sod that withstands erosion from heavy rain showers.

## OPERATIONAL REVEGETATION OF TAILINGS DYKE

### 1. Herbaceous plants

The treatment used in plot 3 was applied to reclaim the first sand slope, grade 22°, consisting of approximately 35 acres.

## A. SEEDBED PREPARATION

Muskeg was hauled during January and dumped at the crest of the slope to provide a coverage of 4". The piles of muskeg were not immediately spread due to patches of ice on the slope. Consequently, by spring they had frozen into a solid mass and required ripping with a D9 Caterpillar tractor before spreading. Levelling and mixing muskeg into sand was done by dragging a crawler pad attached to a steel cable, resulting in a mixture of approximately 50% muskeg and sand.

## B. SEEDING

A seed mixture as used on test plots at 30 pounds per acre, 8-24-24 fertilizer at 400 lbs. per acre, plus 60 gallons per acre of soil oil SSC was applied with a hydroseeder. This method required 14 operating hours to seed 35 acres. Seeding was completed on May 23. Unfortunately, below normal precipitation resulted in a germination and growth rate of only about 55%. Better plant stands were obtained where a tractor or footprints had packed the seedbed following seeding.

Despite the partial drought, plants that survived in the non-irrigated areas (22 acres) produced sufficient growth to stop wind erosion and reduce water erosion. In the irrigated portion (13 acres), no problems were experienced in obtaining a healthy stand of vegetation.

## C. NEW METHODS

Projection of the Long Range Reclamation plan indicated that irrigation would be costly . However, vegetation in the non-irrigated area produced plants that in time would achieve our reclamation goals despite below average rainfall. Packing the seedbed following seeding improved germination and plant growth, and muskeg thoroughly mixed with sand improved the soil structure, percolation and moisture retention.

A Howard rotovator P.T.O. power lift model was obtained to till muskeg into sand. A Brillion grass seeder 8 foot power lift model with fertilizer attachment was obtained to seed, fertilize and pack soil in one operation.

On areas with a slope of 2.5:1, tilling is done travelling down the slope and returning with rotovator idle. The average production rate is 0.4 acres per hour. Seeding is done in a similar manner at approximately the same rate. Slope grades less that 2.5:1 can be worked travelling both directions.

### D. PERFORMANCE

To maintain a healthy growth of forage, all vegetated areas receive an application of a complete fertilizer at 200 lbs. per acre spring and fall. Vegetated areas that had a seedbed prepared by rotovator and sown with Brillion seeder display a more even mixture of grass and legumes and a greater germination rate of legumes. The dyke slope reclaimed in 1971 had areas where creeping red fescue is becoming the predominant species.

## 2. Afforestation

At the beginning of reclamation of the tailings dyke, it was decided that due to the topography, land use would be for wild life habitat. The choice of variety and planting design centres around this concept, calling for establishment of trees.

### A. TESTING CONIFER SEEDLINGS AND SEEDS

In the fall of 1971, 200 spruce seedlings, 100 3-year-old spruce and one pound of jack pine seed were received from the Department of Lands and Forests. The three-year-old stock was planted on an original test plot area, and the seedlings and seed in several areas among 1971 forage. None of the plantings survived, due mainly to inexperience in planting procedures on dyke soil and competition by grasses.

Approximately 1000 jack pine seeds were planted in protected areas among forage only on the hydroseeded section. No germination from seed was observed the following (1972) growing season, largely due to lack of moisture. In the spring of 1972, 135 jack pine were planted in test plots on the first sand slope with an eastern aspect and 13 on the south side of the dyke. Today, 30 plants on the east slope survive in a healthy vigorous condition; the 13 planted on the south side have failed. Further testing is planned for the 1974 season, using native jack pine transplants in test plots with north and east aspects, among freshly-planted vegetation and two-year-old plants.

## B. TESTING DECIDUOUS STOCK

To test deciduous plantings, several test plots (total 12 acres) were designed and laid out among the vegetation on two sand slopes with north, east, and south aspects.

In the spring of 1972 and during the latter part of summer, a total of 4000 shrubs and seedlings of the following species were planted: griffin poplar, birch, caragana, chinese elm, pin cherry, choke cherry, wolf willow, buffalo berry, laurel and acute leaf willow, jack pine.

Sources of supply were: the Provincial Tree Nursery, Department of Lands and Forests and Devon Nurseries, Devon, Alberta.

In October, 1973, the following plants survived, listed in descending order of condition of survival rate: Laurel and acute-leaf willow in one block (other areas of willows rated very low due to rodent damage and dry soil conditions), chinese elm, pin cherry, jack pine, caragana, birch, poplar, wolf willow, and buffalo berry.

## C. OBSERVATION ON AFFORESTATION

Observation on the performance of trees and shrubs during two growing seasons (1972 & 1973) has revealed some factors that may promote plant growth and others that have a suppressing effect.

Trees and shrubs growing in a herbaceous cover containing 30% to 40% legume plants have greater survival rates and seasonal growth than trees or shrubs growing in only a grass cover. Areas of sparse vegetation permit the trees and shrubs to compete for plant nutrients and moisture. North and east facing slopes are more favorable to conifers than south or west facing slopes. Volunteer poplar and birch (native species) have greater survival rates and seasonal growth than imported stock. We plan to test native species in trial plots on the tailings dyke with seedlings propagated this spring by Alberta Forest Services from stem cuttings of balsam, poplar, willow, and dogwood. In 1975, further testing of aspen seedlings from root cuttings, seedlings of black spruce, jack pine, birch,pin cherry, choke cherry, and alder propagated from seed will be conducted.

Some factors limiting plant survival and growth on the tailings dyke were observed. Mice caused mortality by girdling large poplars and pin cherries or eating the poplar and willow seedlings. To check damage, trees and shrubs were sprayed with a repellent which is effective as long as it remains on the plant. Also, tin cans 10" high were placed around many of the trees or shrubs, but in one instance, the mice climbed over the cans to girdle some fine specimens of pin cherries. The best check is natural predators. In the two previous summers, hawks and owls patrolled the areas; wolves and coyotes during winter. This past summer a lynx hunted the areas for a couple months until it was killed by another predator. Also, weasels have been observed hunting in the areas.

There were other limiting factors. Dense grass, creeping red fescue compete with trees or shrubs for plant nutrients. Poor root formation was a problem on poplar seedlings; this is a lesser degree than other factors. Toxic compounds that inhibit or prevent plant growth may be present but have not been confirmed.

## D. OVERBURDEN WASTE DUMPS

Overburden material (clays, muskeg, sand, lean oil sands) removed from the orebody and not used in dyke construction are wasted on spoil piles located in excluded areas. The spoil piles, or waste dumps as they are more often called, receive the greatest damage from water erosion, producing conditions that are difficult and costly to revegetate. To date, no revegetation of the waste dumps has been done and to provide some guidelines, tests are being conducted this winter in the greenhouse of Alberta Environment, Earth Sciences and Licencing Division, Lethbridge, to determine waste material treatments that will help to produce an effective vegetative cover to control water erosion.

Preliminary reports on greenhouse soil tests using soil treatments of clay only, clay plus 20% muskeg, clay plus 20% sand, or clay plus 20% sand plus 20% muskeg indicated that plant growth is approximately equal in a mixture of clay plus muskeg to a mixture of clay plus sand. Better plant growth is obtained in a clay plus sand plus muskeg but not to the extent to justify the addition of either ingredient. Growth in clay only is 50 - 75 percent of the growth in the mixtures.

A five acre area of overburden soil, similar to material in waste dumps, was sown in 1972. Plant performance correlated to the type of soil. That is, heavy grey clay produced stunted, thin stands of grass and no legumes; clay till areas produced more vigorous grass and legumes, and lean oil sand areas remained barren.

## E. CONCLUSION

This paper describes the procedures, methods, material, and equipment used to reclaim the disturbed land resulting from the open pit mining and separation of bitumen from oil sands by the hot water method.

The necessity to stabilize the tailings dyke sands has not permitted the time for research studies and work to determine the most effective materials and methods to use. As more areas are revegetated, it becomes increasingly apparent that research studies and work should be conducted in,

a. The establishment of a herbaceous cover that requires a minimum of maintenance to provide erosion control.

b. The selection of conifer and deciduous varieties for a permanent cover and establishment of a source of supply.

c. The spreading of muskeg on tailings dyke and waste dump slopes.

# PRELIMINARY REVEGETATION TRIALS ON TAR SAND TAILINGS AT FORT McMURRAY, ALBERTA[1]

by

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## ABSTRACT

Twenty-nine species of trees, shrubs, herbs, and grasses were tested for reclamation of a tar sand tailings dyke at Fort McMurray, Alberta. All species were hydroseeded after three different soil preparations: 1 - contour trenches on graded surface; 2 - surface packed with a crawlertractor after grading; 3 - no further treatment after grading.

Grass cover was achieved on the first and second treatment while the seeding on the third treatment failed. The successful grass species were: *Agropyron cristatum*, *A. trichophorum*, *A. latiglume*, *A. riparium*, *Bromus inermis*, *Argrostis alba*, *Dactylis glomerata* and *Phleum pratense*. The seeding of trees, shrubs and herbs was unsuccessful.

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[1] Published in full as Information Report NOR-X-103, obtainable from Northern Forest Research Centre, Edmonton.

# *RECLAMATION OF COAL SPOILS*

# PROBLEMS OF RECLAMATION IN HIGH ALTITUDE MOUNTAINOUS AREAS.

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Reclamation of mined land at Canmore has been in progress since 1969. In that year the first small strip mine was backfilled and in 1970 the same mine was contoured and seeded. Each year since 1969 has seen an increase in the amount of land reclaimed and in the efficiency of the operation. This short paper will attempt to outline the procedures followed and the reasons for success or failure.

The land reclaimed has, except in one instance, been strip mined. All the strip mines have been relatively small due to the very complex geology of the strata close to the mountains. The areas affected have ranged from 10 acres to 35 acres and all work has been done at altitudes between 4,500 and 5,000 feet.

The paper will be divided into three sections each covering a separate reclamation project.

## SECTION I. PROSPECT STRIP MINE

This mine occupied an area of approximately 10 acres and mining was completed in 1968. During 1969 we backfilled the area and contoured the slopes. No top soil had been separated during the mining process and after backfilling we were left with a surface which resembled a patchwork quilt in the variety of materials which had found their way to the surface. These included:

a. Peat - several feet thick
b. A rock pile consisting mainly of carbonaceous shale
c. A silty gravel
d. A mixture of coal and rock and a bench of undisturbed rock.

It was not an ideal site to start a re-vegetation project, but as our first effort, it had one great asset: VARIETY - a variety of surfaces which allowed us to experiment and find out what could be done with each. As a first step the area was mapped out and the type of surface material was recorded. We decided to cover the rock with a layer of about 6" of peat. Apart from this all the other surfaces were left in their natural (or rather unnatural) state. Three different seed mixtures were made up containing from four to seven seed types. These were then spread by hand-operated cyclone seeder in such a way that each type of surface was seeded with each of the three types of mixture. Seed was spread at a rate of 40 lbs./acre and a 10/30/10 fertilizer was added at the rate of 220 lbs./acre. The whole area was then lightly raked by hand. No mulching was done. The cost of this operation including trucking and spreading peat on the rock pile was $210.00 per acre.

We had completed this work by mid-summer and by October of that year there were signs of growth although the vegetation particularly of the silty areas was very sparse indeed. We began to wonder whether the experiment had been a complete failure. Next June the areas where peat had been used were thickly covered with vegetation and after another 12 months, even the vegetation on the silty areas was coming along nicely. Now, three years later, vegetation is well established over the whole area, except for the patches where coal and rock were left. Even here, some vegetation, mainly wild plants, has taken root.

Some of the general conclusions we came to as a result of this first effort can be summarized as follows:

a. A large variety of seed in the mixture is advantageous.
b. Growth is fast on peat, much slower on silty gravel.
c. Even peat excavated from 3 - 4 feet below the original surface provided a good growth medium.
d. Peat did not dry out so far as to kill off the young plants. (This had been one of our fears).

## SECTION II. CANMORE CREEK NO. 1. STRIP MINE

This mine occupied an area of approximately 25 acres and mining was completed during 1970. Two seams were worked, each of them was 12 ft. to 15 ft. thick and they were separated by about 150 ft. of rock. The seams lay at an angle of 80° to the horizontal and had to be mined separately. As a result, when mining was complete, we were left with a pit 120 ft. deep, about 2,000 ft. long and 500 ft. wide. On this occasion alluvial gravel and rock had been separated during mining. Backfilling was completed in time to start re-vegetation in 1971. Those areas where the alluvial material contained a fair amount of silt were left alone. In those areas where there was very little silt in the gravel, a thin layer of peat was mixed with the surface material.

A mixture of seven seed types was used. The composition of the mixture was based on advice received from officers of the Alberta Forest Service and on our experience with the Prospect Strip Mine in 1970.

| Type of seed. | Percentage by weight. |
|---|---|
| Creeping Red Fescue | 30% |
| Pubescent Wheat Grass | 15% |
| Kentucky Blue Grass | 15% |
| Climax Timothy | 10% |
| Red Top | 10% |
| White Dutch Clover | 5% |
| Crested Wheat Grass | 10% |
| Sweet Clover | 5% |

This same mixture was so successful that it has been used for all subsequent work. At Canmore Creek No. 1. we intended to use 40 lbs/acre of seed, but we finished up using 55 lbs/acre. This was partly due to the fact that for the first time we used a hydroseeder. It took our operators a little while to get used to the operation of this machine and the mulcher. We again used 220 lbs. of 10/30/10 fertilizer per acre. Mulching was done with a mixture of straw (one ton per acre) and ashphalt (270 gallons/acre). Our consumption of ashphalt was far higher than had been intended. This was due to mulching during very windy weather in which the operators had great difficulty in getting a uniform layer of straw on the ground. The ashphalt was heated in a tank towed behind the flatbed on which the mulcher was placed, and held the straw mulch in position even in windy conditions. The seeding was found to be a fast process and it was quite possible for two operators to seed 6 - 10 acres in eight hours. Mulching was much slower and we were fortunate if three men could mulch one and a half acres in eight hours in this first year of operation.

The results of our work were very gratifying. Seeding was done in July and by September there was clear evidence that vegetation had taken hold over the majority of the area treated. Some of the things we learned from our first efforts with hydroseeding were as follows:

1. Windy weather is fatal since it prevents an even distribution of seed or mulch. For this reason in subsequent years, we started work at daybreak to take advantage of calm mornings and avoid windy afternoons.
2. The thickness of hay mulch is critical and 1 1/2" seemed to be ideal. Anything less than 1" caused slow germination and anything over 3" seemed to stop germination completely.
3. Damp straw costs a lot of money since the bales have to be broken apart by hand or the mulcher gets clogged.

In 1972 and 1973 the remainder of the Canmore Creek strip and two other strip mines were seeded. A comparison of our costs in the two years 1971 - 72 with the year 1973 is interesting. The figures are given below. All costs include labour, supervision, equipment rentals and materials.

| | 1971 - 72 | 1973 |
|---|---|---|
| Hydro seeding and mulching | $245/acre | $170/acre |
| Spreading top soil including transportation. | $150/acre | $164/acre |
| Cleaning up debris, dead trees stumps etc. | Not recorded | $109/acre |
| | | $443/acre |

The reduction in hydroseeding costs in 1973 was achieved in spite of an increase in the cost of materials between 1971 and 1973 which averaged about 50%.

One mistake we made in 1971 which increased our costs, was to have the hydroseeder following closely behind the dozer we used for spreading top soil and the group of men who were clearing debris from the site. This caused delays in hydroseeding which proved expensive. In 1973 we did not start hydroseeding until the areas had been fully prepared and the effect can be seen on our costs.

## SECTION III. THE BANK OF CANMORE CREEK:

This creek runs alongside the Canmore Creek strip mine described earlier in this paper. Unfortunately, at the time the strip mine was opened up, a spoil heap was formed which extended along the bank of the creek for about 400 yards. This spoil consisted of grey shale and sandstone in all sizes from fine material up to pieces as large as 6 feet cubed. The heap extended right up to the edge of the creek along one side and the spoil had reached a natural angle of repose for the rock of about 40°. The slope length from the creek to the crest of the heap was about 60 feet. Unfortunately, fine material from the slack pile had been carried down the creek for some distance, had settled out in the slower moving sections and had covered the bottom gravel. The result was that the fish population along the section affected by the mining operation was only 10% of that in the upstream area which contained a good population of native brook trout up to 10 inches long, very wary and a test for any angler but unfortunately no match for a spoil heap.

This all happened in 1968 and early 1969, and if it seems to prove that the coal industry destroys every natural thing it touches, bear in mind that at that time most of us, in and out of industry, did not really appreciate the damage we could be doing to our own environment. Rachel Carson had set up one of the first milestones of environmental concern only a few years earlier with her book "Silent Spring" and in 1969 your own Department of the Environment was only a twinkle in Bill Yurko's eye.

Standing on this stream bank and muttering "mea culpa" it was at first difficult to know how to tackle such a very delicate reclamation job. The spoil heap extended right up to the edge of the stream and any attempt to regrade the existing 40° slope to something more reasonable would have resulted in additional large volumes of coal and silt being released into the creek. This would have been a pity since by this time the stream had cleaned away much of the original silting during summer floods. The problem can be summarized as follows:

a. To establish a bed of material capable of supporting vegetation on a rocky slope at a 40° angle to the horizontal.
b. To do this in such a way that even at 40° the soil would be stable and erosion would be avoided.
c. To revegetate the slope.
d. To establish shrubs and small trees which would, as the stream bottom cleared itself of silt and the trout returned, provide cover for the fish population.

It would be simple to truck in peaty soil, pour this down the slope and keep our fingers crossed, but it would be just as simple for the first heavy rain to wash the top soil down the slope. The trick was to get the soil to stick. Fortunately rock over 12" cube was exposed over about two thirds of the slope and would provide enough resting places for soil to rest naturally between the rocks. Over the remainder we used a backhoe sitting on top of the slope to draw the material back until large rock was exposed. Then we used the same backhoe swinging its bucket laterally along the slope to create a few terraces on which soil would rest.

Then peat was trucked in and tipped down the bank until most of the rock was covered. We avoided using silty soil since we felt that it would be liable to erosion whereas the peat would absorb the water rather than allow it to run down the surface.

Several very large rocks had rolled down right into the creek, but these were not disturbed as they were very solid rock which would not weather easily. It was felt they would form a feature of the stream creating pools and holding places for fish as well as helping to scour the creek bottom of silt.

The slope was seeded and mulched. Areas which could not be reached by hydroseeder were hand treated and the work was completed in the summer of 1973. By the fall it appeared that the first growth of grass was well established and fortunately no serious erosion had taken place.

We feel this was the most difficult reclamation job we have completed and hope that restoration of this stream bank will prove to have been a successful operation.

## SECTION IV. GENERAL COMMENTS ON COAL MINE RECLAMATION:

There are some comments I would like to make and some questions I would like to pose all concerned with land reclamation.

Firstly the comments:

1. A very small strip mine with a reserve of 100,000 tons of coal would affect an area of say, about 30 acres, including access roads and spoil heaps. In the mining process this mine might handle 300,000 yards of rock, 100,000 yards of gravel and 100,000 tons of coal. The total dollars spent on excavating during mining and replacing this amount of material during reclamation would be of the order of half a million dollars. This is operating costs only and does not include coal transportation, coal cleaning, overheads etc. For half a million dollars surely we ought to do more than remove the coal, replace the overburden, cover it with grass and walk away from it. Nature is not perfect and just because the land had a certain profile when we started we should not feel obliged or be regulated to reproduce that same profile after mining. What I am trying to say, is that in the process of spending half a million dollars on a very small

mine we should surely be able to create something during the reclamation process which did not exist before.

One of the loveliest gardens in the world, the Butchart Gardens, near Victoria, is an example of what can be done with an old stone quarry. I am not suggesting we can tackle anything so ambitious in terms of vegetation, but I think we could be just as ambitious in another way by developing a recreational use for the land after mining. Strip mines near centres of population could become golf courses, lakes, parks etc., while those in more remote areas give us the chance to seed with vegetation which will encourage game, birds or even berry pickers.

The argument is even stronger with a larger strip mine with a reserve of say 15 million tons where the expenditure on material handling could be of the order of 60 - 80 million dollars.

2. The effect of strip mining on wildlife has often been cited and most often the view is expressed that strip mining threatens wildlife. This is the case where the mine site is situated on wildlife winter grazing areas, but in areas where the tree cover is relatively dense the opening up of patches of trees and their replacement by grass can only be beneficial.

Even where grazing is destroyed the areas directly affected by the mine is usually relatively small. The threat to wildlife arises not so much because of the mining operation as by virtue of the fact that areas previously difficult to reach now become accessible by the construction of roads for exploration and mining.

In my own opinion, where a mining operation is allowed to go ahead, there should be a ban on hunting at least during the life of the operation in the area surrounding the mine. The presence of people is something most of our wildlife can get used to providing the people are not armed with rifles. I realize of course, that this does not apply to species such as the grizzly or the cougar, but elk, moose, wild sheep etc., appear to accept people providing they are not threatened.

3. At Canmore, we have had a tremendous amount of help in our reclamation work from officials of the Provincial Government. Two individuals amongst many who I ought to mention are Jim Wallace of the Alberta Forest Service and Gerry Thompson of the Calgary Fish and Wildlife Division. Jim taught me what little I know about seeding. At the time we started, my only experience was hand seeding my own lawns, done under the direction and observation of my wife, who has to take credit for the turf which resulted. When Jim insisted we could revegetate a silty gravel containing 50% stones, I frankly did not believe him and I was pleasantly surprised when his predictions were substantiated.

   Gerry Thompson helped The Canmore Mines, Limited, with the rehabilitation of Canmore Creek and has worked hard with the mine, and with our Fish and Game Association on the protection of watercourses in the Canmore area.

There are a few problems we are having to deal with, which we do not as yet know the answers:

a. A mine we are backfilling at present is fed by springs and has an average depth of 40 feet of water at present. We backfill using a dozer and this machine can only push broken rock to the edge of the water where it takes up its natural angle of repose (about 40°). It is impossible to push the rock any further so we are left with a steep bank of broken rock which is very unstable to walk on and even if we can successfully make a lake out of this mine, it will not form an attractive shoreline. One solution would be to use a dragline and dump rock into the lake but we do not have such a machine at present.

b. At the same mine, the water in the pit is very cloudy and contains a good deal of suspended matter. This has had no chance to settle as yet, since we are still backfilling. The question is - "when we have completed backfilling and no further disturbance is necessary, what can be done to make the solids settle and clean up the water"? There is a fair amount of insect life in the water now, so it probably is not too polluted.

c. One important question in our seeding operations concerns the mulching process. Seeding without mulching with straw is still effective. From visual observation, there seems to be a reduction in the thickness of vegetation and germination is a slower process. The problem is that mulching with straw is a slow and fairly costly process. We wonder whether the plastic mulches which can be applied along with the seed are effective under our conditions?

# VEGETATIVE RECLAMATION ON COAL REFUSE, BLAIRMORE, ALBERTA

H. Regier, Alberta Environment

A grass-legume-cereal mixture was seeded at various depths into coal refuse and coal refuse treated with sewage sludge, cow manure and commercial fertilizer. The seed mixture consisted of sweet and alsike clover, alfalfa, slender and crested wheat grass, creeping red fescue, timothy, bromegrass, fall rye, wheat and barley.

The seeding rate (number of seeds per square foot) for the grass-legume portion was approximately two times the agricultural rate, whereas the cereals were seeded at approximately one-half the original rate. Light and frequent spray irrigations were applied throughout the growing season.

Germination of the grasses and legumes seemed most complete at seeding depths of approximately one inch. Cereals germinated well from depths of approximately four inches. Shallow seeding seemed unsuccessful due to desication and greater kill due to high surface temperature. Even with high kill, the cover crop, especially fall rye, was advantageous in that quick germination and seedling growth provided protection for emerging grass and legume seedlings.

The sewage sludge treatment produced the most diverse and healthy vegetative cover. In descending order of visual success, the sewage sludge treatment was followed by the treatments cow manure, commercial fertilizer and manure.

In all treatments fall rye appeared dominant. Of secondary dominance were creeping red fescue and the legume group. Other grasses were relatively sparse except where growth conditions were good.

At least in southern Alberta, it seems irrigation is essential for vegetative establishment on coal refuse. Future observation will assess winter hardiness and the ability of the established cover to survive without irrigation.

# REVEGETATION OF STRIP MINED LAND
# at
# NO. 8 MINE
# GRANDE CACHE, ALBERTA

Terry M. Macyk

Soils Division, ALBERTA RESEARCH

## INTRODUCTION

At the request of McIntyre Porcupine Mines Ltd., the Soils Division of Alberta Research began a surface mine reclamation study at No. 8 Mine, Grande Cache in the spring of 1972. The mine is located in the Foothills Region at an elevation of about 5,300 feet a.m.s.l.

## 1 SOILS

The soils which occur in this area under virgin conditions are generally shallow. They vary in depth from 4 inches to 6 feet and overlie consolidated bedrock; the average depth of soil over bedrock is about 24 inches in the area. Analyses of soil samples indicate that the soils are moderately to slightly acid, are medium (silt loam) textured, and have low levels of the major plant nutrients, especially nitrogen and phosphorus.

Prior to the excavation of pit areas, the soil above bedrock is removed and stockpiled for later use. The term "topsoil" is used loosely to describe this material. "Topsoil" in this context refers to the combined A, B and C horizons of the original solum. In other words, it includes all the weathered material over bedrock.

After the coal has been extracted from an area and backfilling and levelling have been completed the "topsoil" is spread on the surface. This "topsoil" is variable in color and coarse fragment content.

### A Topsoil Properties

Soil analyses indicate that the topsoil used for a seedbed has pH varying from 6.0 to 7.9 with most values being in the 7.0 to 7.9 range.

The texture of the "topsoil" is predominantly silt loam with a particle size distribution of about 30% sand, 50% silt and 20% clay. A lack of organic matter results in compaction and crusting occurring readily.

Nutrient analyses indicate that the available nutrient levels are very low. Nitrogen levels are 0 to 1 pound, phosphorus 1 to 20 pounds and potassium about 125 pounds per acre.

## II REVEGETATION TRIALS

Four different sites were selected for experimental plot work. Two sites are located on relatively level backfilled areas. The others are located on the south-west facing slopes of spoil piles, one having an incline of 14 degrees and the other an incline of 40 degrees.

### A Grasses and Legumes

During the two growing seasons of 1972 and 1973, 26 different grass and legume species were applied in 40 different mixtures. The grass seed and fertilizer was applied with a push type or hand operated cyclone spreader. After seeding and fertilizing, the plots were hand raked to incorporate the seed with the soil material.

During the 1972 growing season seedings were done at the end of May, late August and mid-September. The spring planting consisted of a total of 30 plots, each 20 x 30 feet in size. Two plots were seeded with the same grass mixture. One was fertilized while the other was not. The fertilized plots received the equivalent of 200 lbs of N, 275 lbs of P and 200 lbs of K.

A preliminary assessment of species performance and the effect of fertilizer was possible and thereby allowed for the elimination of certain species. For the August and September plantings all plots (12) were fertilized. The September planting was unintentionally done on four to six inches of snow.

In 1973 plantings were done during the month of May, in mid-July and late August. A total of 43 plots were established to assess species performance and response to varying fertilizer application rates. Additional plots were established on a portion of a 40 degree slope in the area. A soil stabilizer was used to protect the soil surface from erosion.

### B Tree Seedlings

In mid-June of 1972, 100 three-year-old "bare root" and 500 one-year-old "peat sausage" container-type lodgepole pine seedlings were planted. The container seedlings had the thin plastic skin removed, not removed, or perforated before planting.

In 1973 about six hundred one-year-old white spruce "peat sausage" container seedlings were planted with the skin removed.

### C Shrub Cuttings

Cuttings from alder, buffaloberry and willow were collected at the minesite and an attempt was made to root them in the greenhouse. The willow cuttings rooted successfully while the alder did poorly and the buffaloberry did not root at all. Those cuttings which did root successfully in the greenhouse were planted on a south-west-facing slope (area III).

### D Greenhouse Trials

Greenhouse trials were conducted mainly to determine germination rates of commercial seeds planted in fertilized and unfertilized soil from the minesite. More recently, seeds collected from native species in the area have been planted in the greenhouse.

## III RESULTS

### A Response of Grasses and Legumes to Fertilizer Application

The results indicate that fertilizers, especially nitrogen and phosphorus will be required to establish a reasonable cover of grasses and legumes. There was a significant difference in growth between those plots which were fertilized and not fertilized (1972). The fertilized plots produced 10 to 20 times more dry matter than those that had not been fertilized.

### B Winter Hardiness and Species Suitability

Of the grass species introduced in 1972, the following appear best suited for revegetation purposes: crested wheatgrass (Fairway), Russian wildrye (Sawki), bromegrass (Carlton) and Boreal creeping red fescue.

Initial observations indicate that of the species seeded in 1973, the following appear the most suitable for revegetation: intermediate wheatgrass, perennial ryegrass, slender wheatgrass, hard fescue, nugget bluegrass and Erica creeping red fescue. A more valid assessment cannot be made until this coming summer.

### C Evaluation of Optimum Seeding Time

On the basis of observations made to date, the plots planted in the spring are superior to those planted in the fall. From the fall planting, few legumes were evident the following spring. This suggests that legume germinants are more susceptible to frost than are the grass. Planting in spring provides the advantage of a full growing season,although there is some risk of frost involved.

The unpredictable weather in the Foothills makes timing of a fall planting difficult. If the planting is done too early in the fall the seed may germinate and be highly susceptible to winter kill. On the other hand,a planned seeding may be cancelled by a heavy snowfall. It should be noted,however, that the grass species seeded on 4 to 6 inches of snow in September 1972, germinated the following spring and did not appear to suffer any ill effects from the procedure. However, none of the legume species survived.

Mid-summer seeding is not recommended because the soil surface tends to remain dry and crusted for extended periods. The result is slow germination and high seed losses to wind action.

### D Revegetation of Steep Slopes

The attempt to revegetate a 40 degree slope met with only limited success. The grass tended to grow in isolated clumps around stones or in small hollows. In summary, the factors contributing to the minimal success in revegetating steep slopes are:

1) the instability (creep) of the topsoil surface.

2) the relatively smooth surface does not provide sites that would hold the seed and fertilizer for a sufficient period of time to permit germination.

### E Tree Seedlings

Observations in 1973 indicate that the "bare root" seedlings have a survival rate of about 25% with those surviving showing good vigor.

The "peat sausage" container seedlings showed varying survival rates depending upon whether or not the thin walled skin was removed, not removed,or perforated before planting. The skin-off treatment has the best survival rate of 54%.

Most of the container seedlings that did not survive had been heaved out of the ground by frost action.

### F Shrub Cuttings

Eighty willow and five alder cuttings rooted successfully in the greenhouse and were planted at the mine-site on a south-west facing slope. The use of cuttings in revegetation work will be more fully investigated this year.

## IV OTHER OBSERVATIONS

### Effect of Micro-depressional Sites on Plant Establishment

The occurrence of micro-depressional sites resulting from the movement of machinery appears to optimize germination and the growth of the plants. It has been observed that where caterpillar tracks occur the plant growth is superior to that in the remainder of the area. These sites provide better soil moisture conditions and protection from the wind than the surrounding areas.

Tree seedlings also exhibit increased survival rates when planted in roughened areas where some protection from the winds is provided.

## V RESEARCH REQUIREMENTS

The results obtained during the past two years provide some basis for future reclamation research. However, much more research will be required to provide reliable answers to the many questions and problems.

1) More time is required to evaluate the actual suitability of using commercial species in revegetating high elevation areas.
2) More time is required to determine long term fertilizer requirements.
3) More research is required to develop feasible means of revegetating major areas with native species, especially the grasses and herbs.
4) Undoubtedly the most difficult problem to be solved is that dealing with developing suitable methods of revegetating steep slopes.

# EXPERIMENTAL TREE PLANTING ON ESTEVAN SPOIL BANKS--SASKATCHEWAN

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## History:

In 1949, the first test plantings were done on spoil banks in the Estevan area in the southeastern corner of Saskatchewan. The plantings were very limited in nature, and success or failure only judged on whether the trees lived or died. Very few survived.

Other small plantings were undertaken periodically through to 1957. These plantings were only inspected when someone happened to be in the area, as Estevan was a considerable distance from other areas of tree planting activity.

In 1963 the Forestry Branch of the Department of Natural Resources was asked to develop a limited program of experimentation to study the possibilities of introducing tree cover in the Estevan Spoil Banks. I must emphasize here the word "EXPERIMENT" as that is what was done. No mass plantings were ever done.

The Forestry Branch Research Forester at that time investigated the situation and developed a study to examine the area and conduct experimental tree planting on an annual basis, trying different trees and shrubs in various local environments.

## Work Program:

Successful afforestation work on surface mined areas south of the Great Lakes in the United States had been frequently set up as an example of what should be done at Estevan. Examination of reports on work done in the U.S.A. indicated a not too dissimilar climate, with the main differences being the mean minimum temperature and the annual precipitation, approximately twice as much in the U.S. situation as at

Estevan. However one distinct difference did exist--the pH of the soil. In the U.S. they were working with an acid soil condition, whereas at Estevan there is a saline situation with a high pH (up to 8 or 8.5). (The salinity manifesting itself in salt "snow" on the surface along the lakes during dry periods in the summer).

From preliminary examination of an area of spoil piles 25 to 30 years old, the main problems emerged as follows, with regard to tree growth:

1) The presence or absence of salinity and its influence on some tree species;
2) The nutrient problem in general;
3) Influence of the reaction of pH of the soil on some tree species;
4) The influence of the absence of organic matter on some tree species.

Planting:

A small planting was done in 1964 and initially, considering the dry valleys to be almost impossible for survival, planting was done adjacent to small lakes that had been created in the spoil areas. Indications from preliminary investigations of soil moisture, length of exposure to the sun, air and ground temperatures and evaporation, pointed the way to using North and East facing slopes for test plantings.

Vegetation showed that the distance up the slopes from the water was also an important consideration in plant survival.

Four species were used (being all that were available): Siberian elm, hybrid poplar("44-52) cuttings, green ash and Scots pine. The trees were planted in rows 1', 2' and 3' above the level of the lake, and organic matter was added to half the trees planted. With the exception of the poplar cuttings, survival was exceptionally high in both the untreated and treated plants. However, survival in the rows 2 and 3 feet above the lake was better, probably showing the effect of the salinity in the soil near the water. The addition of organic matter seemed to have some effect, but the test was too small to have any real significance.

In 1965 a further planting was conducted, adding to the previous mentioned species--Eastern Cottonwood *(Populus deltoides)*, (local cuttings), Russian Olive *(Eleagnus Angustifolia)*, Hawthorn *(Crataegus rivularis)* and a willow species. Keeping in mind the two main factors of moisture and salinity, all the planting material was put at one-foot vertical intervals on slopes of eastern exposure, starting one foot above the water, and ranging as high as six feet.

Green ash and Siberian elm survived well at all levels. Hybrid poplar and the local cottonwood survived well up to the 4-foot level. Scots pine survival is very poor at the lower levels, but increases up to the 5-foot level, and remains the same at the 6-foot level. The Russian Olive survived well at all levels, as did the hawthorn. The local willow showed requirement for a very moist soil.

Survival of 1964 plantings remained good, with the exception of Scots pine. All species, however, showed signs of chlorosis.

In 1966 and 1967 further plantings were done, using the same species. Survivals were directly related to the precipitation. In 1966, there were three periods when the plants were in a drought condition, and in 1967, a very low rainfall gave a drought situation from May until on into September. (See Climograph). Survivals of newly established plantations in these years were very low. In earlier plantations survival was also reduced, however the addition of the organic matter was quite evident for all species in the 1965 plantation. Presumably there was more moisture retention around the root zone.

During 1966 the Research Forester spent considerable time studying plant communities in the area. Four distinct groupings were recognized. Two of these plant communities--one indicating an extremely dry situation, and the other, very saline depressions, were not suitable for tree growth. The third (Brome-Reed Grass-Wild Rye) encountered in the fresh to moist locations in the valley bottoms, deep saddles and along the lake shores, seemed to be the most promising for planting. The 1967 plantings were done in this plant community, but as mentioned above, the long drough period caused high mortality and so no direct conclusions as to the relationship to the plant community was obtained at this time.

The fourth community was the very moist to wet depressions, and could not be considered for planting unless willow species were used.

Levelling and Planting:

Experimentation to date had determined that some tree species could grow in specific environments within the spoil banks, but it was of little use to plant before the ridges were more or less stabilized and covered by some vegetation. In 1968 funds were appropriated, a D8-H cat was hired, and approximately 11 acres were levelled ($60/acre) By levelled, I mean the tops of the ridges were flattened to a width of about 15 to 20 feet, and the bumps and saddles evened out. An attempt was made to have two profiles in the levelled tops: 1) flat with ridges along the edges; and 2) slightly dished to hopefully retain moisture.

I might mention here that the Saskatchewan Power Corporation did an extensive levelling operation on some piles, costing up to $200 per acre. Following the levelling, they plowed furrows and added topsoil prior to planting trees. Weed growth was excellent, but tree survival was limited. The remaining area between the rambling tree rows was seeded to grass with reasonable success.

In 1969 planting commenced on the levelled spoil piles, using the same species as had been used previously, but adding a few more poplar hybrids. Survival ranged from 56% for the poplars, to 80 to 90% for the rest of the species. The survival on the flat was slightly higher than the dished. This may have resulted from too much moisture, as precipitation in 1969 was excessive.

This high precipitation caused washing and flooding, which played havoc with the earlier plantings along lakes and up the slopes. (Most of the trees at the one-foot level were lost).

In 1970 and 1971 larger plantings were undertaken on the levelled tops, and in favourable plant communities. A larger number of poplar clones (14) were used, some trees and six shrub species. Several willow clones (18) were planted in a favourable plant community, and in a moist east-west valley.

In 1972 the clones of poplar and willow showing the best promise from previous tests were planted, poplars on flattened piles and willows in the moist valleys.

Survival and growth of these plantings have been checked annually, and found to be very favourable. Excellent moisture conditions during these years will have contributed greatly to the good survival. In each successive year, 1971 and 1972, only those clones of poplar and willow showing the most promise from previous plantings were used.

General findings with regard to tree species show the following to be the most successful for planting in the Estevan area in terms of survival, total height and vigor:

1) Russian Olive: Good survival and growth.
2) Manchurian Elm: Fair--limited to better sites, organic matter added--desirable.
3) Hedge Rose: Good survival, fair to poor growth.
4) Scots Pine: Fair on higher levels, on better sites and with organic matter added.
5) Willow: Use rooted stock in moist to wet valleys. The following clones are recommended:
    1. *S*. *Elegantisima* *pentandra*
    2. *S*. White
    3. *S*. Acute
    4. *S*. Black
    5. *S*. *Alba* *vittelina* purp.

6) Poplar: Use rooted stock--clones recommended:
1. P. Canadensis grandifolia
2. P. Petrowskiana
3. P. Griffin
4. P. Northwest
5. P. Wheeler #4

7) - Hedge rose
- Common chokecherry
- Buffaloberry.

Recommendations:

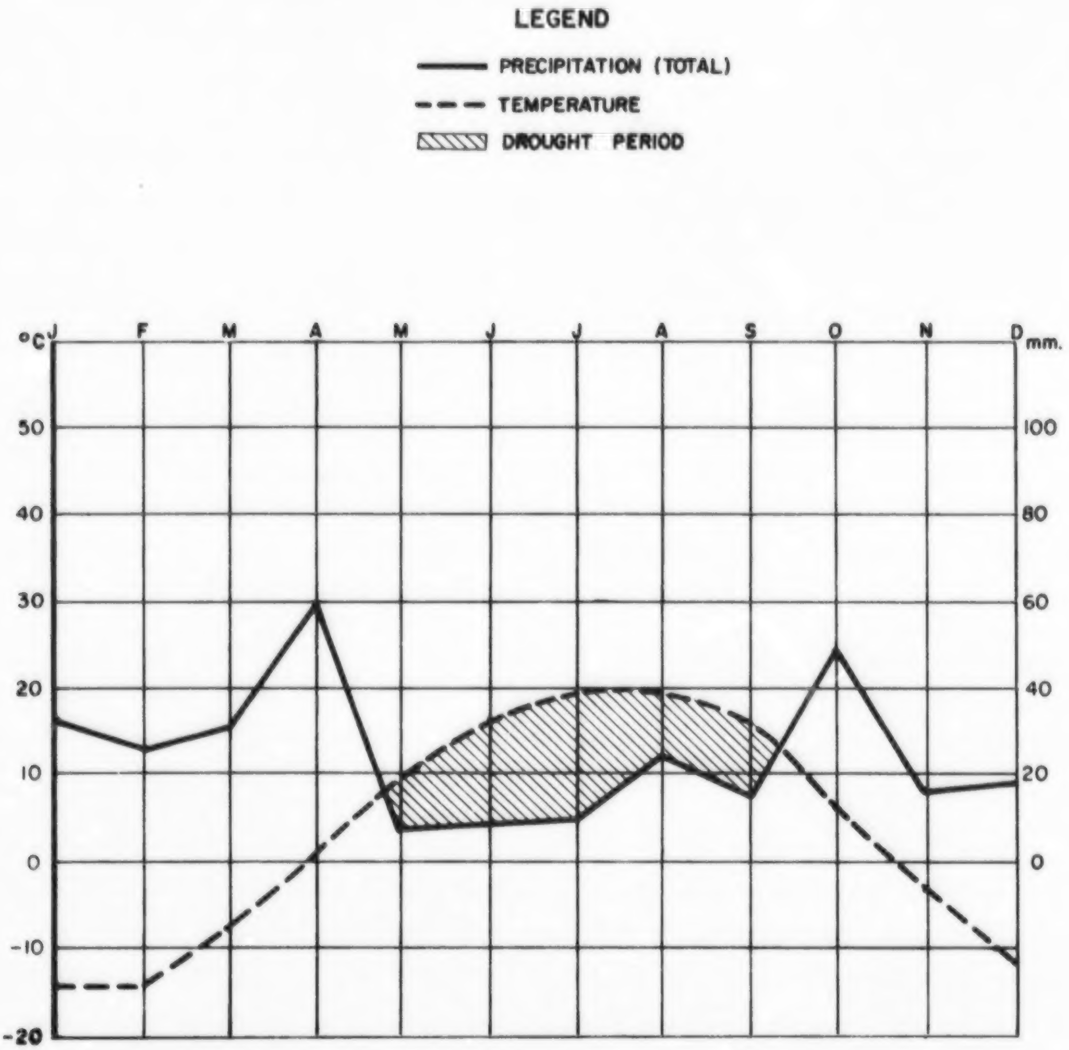
1. On existing old piles, trees can be established on North and East facing slopes.
2. As water levels in the lakes fluctuate, planting should be not closer than 1.5 feet vertical above the water level.
3. Existing plant communities can be used as indicators of where to plant trees.
4. If a greater proportion of any spoil area is to be treed, levelling is necessary to provide quicker soil stabilization and a better site for tree planting and growth.
5. The incorporation of organic matter is beneficial for both survival and growth. If it were possible to convince the mining company, it is suggested that the surface soil layer should be in some way preserved for placing on top of the levelled spoil piles, rather than buried and mixed, as is the case now.

In conclusion, I would say that, in any disturbed area such as I have just been talking about, very serious thought should be given to "what use is going to be made of the area," e.g. people-oriented recreation, wildlife habitat, or a grazing area for cattle. Once this is decided, then the degree of reclamation can be determined and the method chosen.

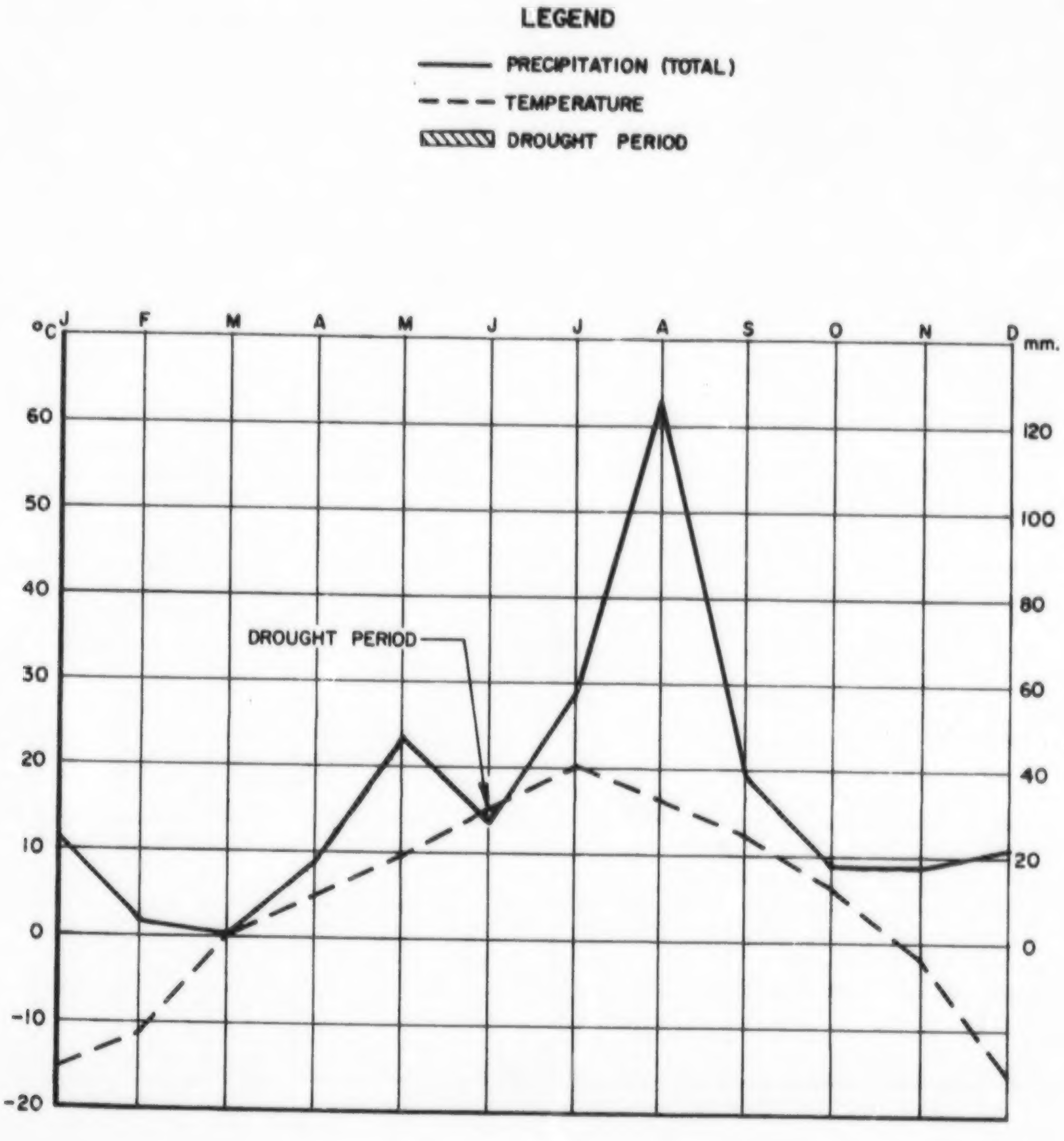
An area to be mined should be assessed for the value of the use before mining, and plans made to restore the area to at least the same value after all mining in the area is completed, and the product taxed accordingly to provide funds for the reclamation to that value.

Reclamation can be expensive and the extent of work done is directly proportional to the purposes for which the area is required.

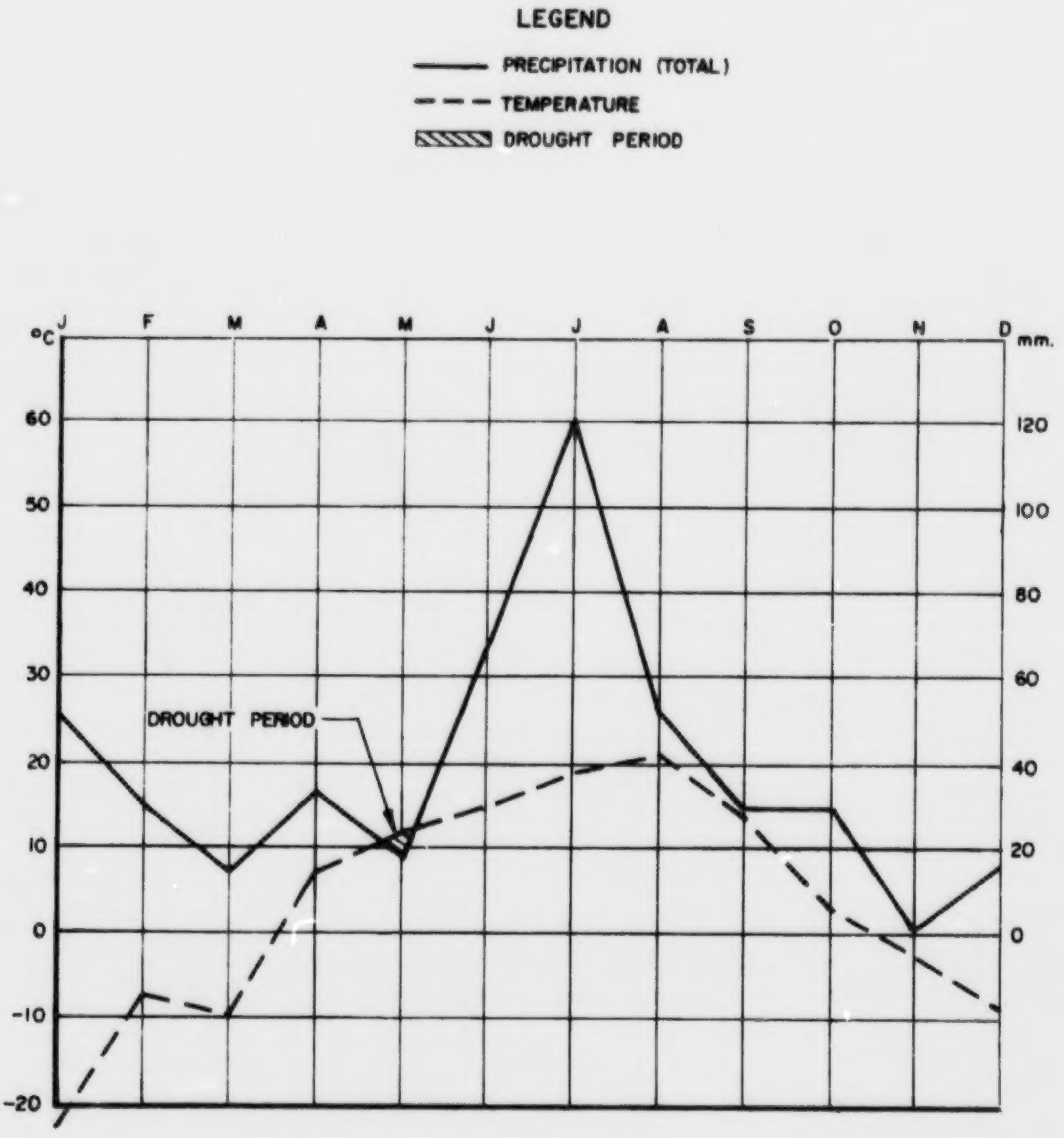
# SIMPLIFIED "WALTER'S" CLIMOGRAPH FOR ESTEVAN 1967



# SIMPLIFIED "WALTER'S" CLIMOGRAPH FOR ESTEVAN 1968



# SIMPLIFIED "WALTER'S" CLIMOGRAPH FOR ESTEVAN 1969



# SPECIES SELECTION, SEEDLING ESTABLISHMENT AND EARLY GROWTH ON COAL SPOILS AT LUSCAR, ALBERTA[1]

by

G.L. Lesko, H.M. Etter and T.M. Dillon

Northern Forest Research Centre, Canadian Forestry Service,
Department of the Environment, Edmonton, Alberta

## ABSTRACT

Thirty different species including grasses, herbs, shrubs and trees, were hydroseeded on coal mine spoils at Luscar, Alberta. The seedings were carried out on different grades of slopes and on rough graded or bulldozer packed soils. Observations showed that only grasses and herbs succeeded in germination and establishment in significant numbers. The number of established seedlings declined sharply with increasing grades of slope. Germination and seedling establishment took place mostly in depressional microsites, because they contained 16.7% more water on the average than the non-depressional microsites.

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[1] Published in full as Information Report NOR-X-117, obtainable from Northern Forest Research Centre, Edmonton.

# *SUMMARY REMARKS*

# SUMMARY REMARKS

D. L. DABBS, Canadian Arctic Gas Study Ltd.

The large number of papers presented at the workshop is indicative of the interest and concern with the problems of land reclamation. Because of the large number of competent biologists, agronomists, pedologists, and microbiologists now involved in reclamation research, I feel confident that the problems of land reclamation associated with the proposed major development schemes in Alberta can and will be solved.

Though a large number of topics related to reclamation were covered, we confirmed the points made by Dr. Smith in his opening remarks, that the state of the science is still in its very early stages of development and that a great deal of research remains to be done. Dr. Smith identified four major areas in which we lack adequate data. First, we've only started to work on the practical utilization of native colonizing species for reclamation purposes. Preliminary work on the transport of metal ions indicates we are facing a potentially serious problem in some areas, but a full understanding and solution awaits more research. Much more work must be done in the field of soil chemistry and microbiology in the restoration of soils. Based on the papers presented at this workshop, work has not yet started on answering his fourth point, that of restoring the water table following a major land disturbance.

Notwithstanding the limitations of the science at this point in time, the future does look good considering the number of research projects underway in the province. This, however, serves to emphasize an important point. Many of the participants at this workshop for the first time met other researchers in this same field and learned of the work they have underway.

The need for central co-ordination and a unified approach to problem identification and information exchange showed clearly during the course of the two days of discussion. If any one recommendation can be made following this workshop, to government and industries in Alberta, it is the need for a central co-ordinating body for land reclamation research and information dissemination. Such a vehicle would result in the maximum return for research money invested in the sense that all groups involved would benefit from the results and unnecessary overlap of research could be avoided.

The need for information regarding the economic aspects of reclamation was recognized by the group. The cost of research, the cost and availability of materials (specialty seeds), the cost of application, the standards required by government which affects costs, and the cost of maintaining a revegetated cover are not well understood by most people in management and research positions. Again, central co-ordination for data exchange and market updating would be valuable.

In closing, I look forward to the next workshop in a year or two when we again present the findings of more advanced research on disturbed land reclamation.

# *APPENDICES*

# APPENDIX 1

## ADDITIONAL PAPERS PRESENTED, NO TEXT AVAILABLE

The status of regulation development for reclamation in Alberta.

Dave Gladwin

Soil characteristics of disturbed areas in relation to vegetation.

Don H. Laverty

The objectives of reclamation, and the achieving of them.

R. (Bob) Webb

Growth chamber studies in establishing vegetation on tailing sands. from the Athabasca Tar Sands.

Don H. Laverty

## APPENDIX 2

## PLANNED RECLAMATION PROJECTS 1974/75

### D. N. GRAVELAND

### ALBERTA ENVIRONMENT, LETHBRIDGE

Projects - observation of coal refuse reclamation in Crow's Nest Pass and strip mine reclamation at Three Hills.

We are committed to provide technical guidance to the Department of Environment for any reclamation projects which arise.

Plans in the Pass for 1975 are to utilize sewage effluents to reclaim an area below Bellevue provided the new lagoon is on schedule.

Research - Tar Sands area - have completed preliminary studies on types of materials encountered, interaction of fertilizer and peat on growth. At present a study is underway to measure the nitrifying power of peats and the trace element requirements of the subsurface materials. Intentions are to study nutrient recycling on present reclaimed areas and if possible to continue chemical and physical characterization of various subsurface soil materials.

### J. SELNER

### ALBERTA LANDS AND FORESTS

1974/75 Reclamation research will be carried out by the AFS in two different areas.

A. Reclamation Research on Athabasca Tar Sands

B. Reclamation Research on coal mined land.

A. Reclamation Research on Athabasca Tar Sands has been undertaken in 1974. The objectives of this research are as follows:

1. To find suitable tree, shrub, grass, and legume species for reclamation of tar sands mined areas.
2. To compare different timing and different methods of tree planting.
3. To evaluate different treatments of planting media and find which is best for vegetation establishment and survival.
4. To evaluate differences between alkaline and acidic materials and find the suitability or unsuitability for different species.
5. To compare survival possibilities for vegetation planted on waste dump material and tailing sand.
6. To compare differences in planted tree mortality on control plots and plots covered by muskeg.

This project results from the discussions at the two meetings held between the Tar Sands industries and government representatives at Fort McMurray on December 13, 1973 and February 15, 1974.

B. Reclamation Research on Coal Mined Land

1. Fertilization Program at Sterco and Lovett.
2. Reclamation for grass land at Luscar, Caw Creek Ridge, Racehorse Creek, Copton Ridge, and Canmore.
3. Reclamation for afforestation at Coal Valley, Luscar, Racehorse Creek and Canmore
4. Reclamation research on steep slopes at different slope gradients in the Crowsnest Forest and Canmore.
5. Research on Chlorosis, soil samples will be taken and anlysed from reclaimed localities which received fertilizer treatment in 1973 and did not receive fertilizer in 1973.

## CLAUDE WHITE

## CARDINAL RIVER COALS LTD.

As in the past, the steps that will be taken at Luscar will be to place spoil at the desired slopes, to backfill the open pits to the limit of the highwall and to terrace and set the drainage patterns.

The slopes will not be steeper that 26.5 degrees, since they would then be subject to rapid water erosion.

Revegetation will then follow immediately after contouring. Curasol and tylose adhesives will be added to help stabilize the seed mixture on the steeper slopes and mulch will be added to moderate the surface conditions.

A typical mixture at Cardinal River Coals should consist of the following items:

1. Curasol AH - up to 30 gallons per acre.
2. Tylose 666 - up to 75 pounds per acre.
3. Curasol AK - up to 30 gallons per acre.
4. Fibre Mulch - 800 - 1,000 pounds air dry per acre.
5. Peat Moss - 4 cubic feet compressed per acre.
6. Fertilizer - 300 pounds chemical and 200 pounds organic per acre.
7. Seed Mixture - up to 60 pounds per acre.

It is expected that approximately 60 acres will be reclaimed in this manner for the 1974-1975 period at Cardinal River Coals Ltd.

## J. H. HAMILTON

## HOME OIL COMPANY LIMITED

### Future Reclamation Research

It is the intention of Federated Pipe Lines Ltd. to underwrite a research project on reclamation of soils damaged by oil spills. A brief outline of the project is as follows:

Objectives

(a) To test the effectiveness of different reclamation treatments in establishing plant growth and in speeding up the breakdown of soil.

(b) To assess the environmental effects of reclamation treatments (effects on soil pH and salt content, and on quality of run-off water).

(c) To prepare a manual for use by field personnel in reclamation of soils as a result of soil spills. This manual would contain information on (1) the techniques and materials needed for reclamation of soil from different types of spills, and (2) estimates of time of recovery of soils and plant growth in different situations.

Work Plan

It is intended that field tests be conducted at four existing spill sites as follows:

(a) Two sites in Swan Hills.
(b) A site at Morinville.
(c) A site in Southern Alberta.

Each test site will involve an area of from two to three acres. The Field tests would involve different soil treatments and planting of different grasses or crops. Determinations will be made of the germination, health, and yield of plants; the breakdown of oil; some chemical characteristics of the treated soils; and, where applicable, the quality of run-off water.

Laboratory experiments will be conducted to find the amount of fertilizers, etc. needed to break down a given quantity of oil and to better define the soil conditions (pH, moisture, temperature) and types of fertilizers needed for the most rapid breakdown of oil. Other laboratory experiments will be conducted to compare the rate of breakdown of different types of crude oil.

The entire project will be carried out under the direction of Drs. W.B. McGill and M. Nyborg of the Soil Science Department, University of Alberta.

# APPENDIX 3

## FUTURE DIRECTIONS AND PRIORITIES

G. L. LESKO

Northern Forest Research Centre

The recommendations below include research needs which I deem important in the successful reclamation of disturbed land, but have not received the deserved attention to date.

1. Research towards planning of the landsurface after the termination of mining operations.

Landforms and landsurfaces left by mining operations are permanent features of the land, and they will limit the land use possibilities for indefinite time. Therefore the planning of final land forms and surfaces to allow high value land uses is of utmost importance.

2. Research towards the improved logistics of mining operations and material movements.

The present logistics of tar sand mining results in the burial of organic soil materials and tills into the bottom of the mining pit and in spreading the sterile tailings on the surface. A new logistics should be found for the entire operation which would put the more valuable materials on the final land surface. This effort would include the solution of problems in material movement and intermediate storage.

3. Reclamational problems of drained tailing ponds.

The future of the tailing ponds is not clear to me, but it is possible that some will be either artificially or naturally drained and will pose a dry land reclamation problem. Methods of soil amelioration and suitable plants for revegetation should be ready when the problem occurs.

4. Reclamation of lean tar sands.

Present mining operations will create some land surface covered with lean tar sand. This material has a much higher bitumen content than the tailings and will pose special problems in reclamation.

5. Propagation methods for native pioneer species.

The use of native pioneer grasses, herbs and shrubs in disturbed land reclamation is desirable. However, the lack of seeds or other propagation material severely restricts their use even for research purposes. The problems related to the large scale production of seeds and cuttings must be solved to make these important reclamation materials available. Methods must also be worked out to inducing the germination of seeds which are normally dormant for one or more years after maturation.

Research to land surface planning and material movement and management needs priority because the outcome of all subsequent reclamation effecrts are depending on these factors.

## J. H. HAMILTON

## HOME OIL COMPANY

It is suggested that considerable research is required in the area of soil erosion as a result of disturbances. This is a problem faced by numerous industries but especially lumbering, mining, and petroleum. Research in this area which would result in some guidelines for road building, well sites, mining sites, pipeline installations, etc. in erosion prone areas, would be most beneficial. It is suggested that such research work should include guidelines for minimizing the erosion resulting from soil disturbances in various types of soils, stabilization of eroding soils, seed types for different types of soil found in erosion prone areas.

# RECLAMATION RESEARCH DIRECTIONS AND PRIORITIES

Terry M. Macyk
Soils Division
ALBERTA RESEARCH

Reclamation research in Alberta is still in its early stages but based on the papers presented at the Workshop one could state that a good start has been made and that a concerted effort in the future should bring many of the problems under control.

The comments I will make in the following text are intended to cover reclamation in general, however some will be directed primarily at strip mining for coal in the Foothills and Mountain Regions.

Before an area is developed for resource extraction a survey of its pre-mining characteristics should be done. The study should provide fairly comprehensive data on vegetation, soils, and groundwater. This information is necessary to provide a record of pre-disturbance condition and will serve as a guide to the probability of successful reclamation. For example, a soil survey in an area in the Foothills destined for strip mining will enable the operators to determine the amount of "soil" material that will be available for covering the overburden prior to revegetation. I am aware of several firms that are already doing these types of studies and suggest that such a procedure should become an integral part of every reclamation project.

The method of revegetation and its success depends largely on a knowledge of the characteristics of the material to be revegetated. Such material should be appraised for its various chemical and physical properties including particle size distribution, total and available nutrient content, organic matter content, pH, moisture-holding capacity, porosity and bulk density. Here again, many firms are already doing this characterization to some extent. A set of standard analyses should be prepared and provided to the companies doing reclamation work.

A knowledge of the local climate is important in planning revegetation. Climatic conditions are quite well defined in the populated and agricultural areas of the province, but coal mining in particular is expanding into high elevation areas where the climate is relatively harsh and unpredictable. Although some meteorological data is available from

Forestry lookout towers this data does not provide a reliable indicator of the climate at the mine site where reclamation work will be concentrated. In addition to the air temperature and precipitation data collected, soil temperature data, especially for the top 50 cm. should be recorded.

The ultimate goal in revegetation is the development of a self-sustaining vegetative cover. Many of the papers at the Workshop described the use of introduced commercial species of grasses and legumes along with commercial fertilizers. Most, or all of the projects have not been of sufficient duration to firmly determine the suitability of the various species nor has there been enough time elapsed to accurately determine fertilization and refertilization needs.

Under relatively severe climatic conditions and for aesthetic reasons native species may be more suitable for revegetation purposes. Presently, revegetation with native species is limited by seed and seedling availability. This creates problems for those firms that are required to reclaim now and not two or five years from now. They have little alternative but to use what is available to them - tame commercial species. At the moment tree seedlings are being used in revegetation in areas outside their natural range and it is apparent that for the next few years it will be difficult to obtain suitable stock. Several mines for example, are located in areas and at elevations for which the provincial nursery cannot presently provide adequate stock. An accelerated seed collection program in these high elevation areas will be required if adequate supplies of planting stock are to be available in the near future. This appears to be a problem that will require government and industry co-operation to solve.

Research is required in the propagation of shrub species suitable for extreme climatic and soil conditions, primarily through the use of cuttings. Some work in plant breeding in the development of hybrids of indigenous species should be emphasized.

Revegetation of steep slopes is a serious problem, especially in the Foothills and Mountain regions. Techniques to establish persistent vegetation on steep slopes have not as yet been developed and are certainly required. Hydroseeding techniques presently used do not appear to provide a solution to the problem.

## PRIORITIES

The following provides a list of what I feel should be the priorities in reclamation research:

1) Co-operation between government and industry to provide an adequate supply of suitable seed and planting stock for revegetation purposes.

2) Development of a suitable (economically feasible) method of establishing vegetation on steep slopes.

3) Make good quality pre-mining surveys of soils, groundwater and vegetation a requirement of any resource development.

4) Require companies to accurately and diligently record meteorological data for their development area.

## APPENDIX 4

# RESEARCH WORKSHOP
# ON
# RECLAMATION OF DISTURBED LAND IN ALBERTA

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